THE HISTORY OF THE STEAM-ENGINE,

FROM THE

SECOND CENTURY BEFORE THE CHRISTIAN ERA

TO THE

TIME OF THE GREAT EXHIBITION.

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PREFACE.

THE amazing and exhaustless resources of Steam Power, exemplified in the progress of national and international communication among all the enlightened countries of the world in the present day, naturally lead us to inquire into its origin and its history. People do not like to sit down in supine ignorance of the nature and operations of an agent which bids fair in a few years completely to change the aspect of the globe. They desire to know, after a time, what were the causes which led to the improvements in the arts, the sciences, and the system of locomotion which signalise the present century. They will accordingly delight to read of the early efforts of man in endeavouring to subject the powers of steam to his controul; to observe the nascent germ of an invention which has multiplied his resources beyond all conception; and to trace it in its progress from the first rude apparatus of the early experimenter, to the beautifully-finished engine of the accomplished inventor and self-taught mechanician.

This little volume is intended to supply the want of a cheap and popular History of the Steam-engine, and to give such details regarding its origin and progress as might interest every reader, without taking up too much of his time and attention with minute and wearisome technicalities. The discussion of subjects connected with steam power and its applications cannot but be interesting to the inhabitants of

this country, where the real steam-engine was first invented and perfected. For to the ingenuity, skill, and perseverance of British artizans, and to the liberal and enterprising spirit of British merchants, is the world at large indebted for the vast advantages derived from our present systems of steam navigation and steam locomotion. Still much remains to be done in order to remove the apprehension as well as the reality of the dangers which hover around these applications of the power of steam; and it is highly probable that, looking back upon its past history and services from the pinnacle of eminence which it has now reached, something may be gained in the shape of more steady and sure precautions in its use, and more determined control over its operations.

The lamentable disasters which continue to befall our steam vessels, and the equally alarming accidents which frequently occur on railways, plainly indicate that our captains and engineers are still ignorant of the true theory and much of the practice of the steam-engine. This theory is not yet regularly taught in our schools and institutions; and the men to whom we trust our lives and property are still left to pick up their information and their practice in any manner they best can; and it is never ascertained by a strict and regular examination, whether they possess such a knowledge of the subject as fits them for taking the management of a steam vessel or of a railway carriage. The usual mode in which engineers at present acquire their practical knowledge, is by the *Rule of Thumb;* that is, they are taught to follow implicitly the practice of the workshop or manufactory in which they have been trained, whether that practice may be right or wrong, or whether it may suit, or not, the circumstances of any case in which they may afterwards be placed; so that, with few exceptions, they continue to act wholly ignorant of the philosophical principles on which the steam-engine is constructed and applied.

It has been justly said by an officer of the Royal Navy, that " whatever of dash, whatever of enterprise, whatever of

combined prudence and skill is to be performed in a future war, will be performed through the agency of steam. The high road to distinction and fame will be found on the paddle-box of a steamer; but to gain this fame, to achieve this distinction, it is indispensable that officers should add to a thorough knowledge of seamanship and gunnery, a knowledge of the steam-engine, an acquaintance with the power which is to be their right arm and strong staff." Unquestionably, steam vessels will be employed by every belligerent nation in Europe, should the balance of power be once broken, or should the aggressions of one power against another ever excite a partial or a general war, the greatest of human calamities. But, as far as human agency is concerned, it is manifest that the fate of war, happen when it may, will then be decided by the question as to which nation possesses the greatest steam fleet, and the best managed steam vessels. The empire of the sea no longer resides in wooden walls, but in the power of steam!

Independently, therefore, of its vast utility to the industrious and manufacturing population of this country, it is evident that the safety of the trading and travelling portion of the community, and the success of British enterprise, whether in the time of peace or in the time of war, demand that immediate instructions be given to our captains and engineers in the proper application and management of the power of steam; and that a series of examinations be instituted from time to time as to their progress in this species of knowledge. An institution for this purpose should be at once established by Act of Parliament, and at the expense of the nation. Government would then find that its power and its safety rested on the knowledge of the people; and were it once known that all captains and engineers must be subjected to an examination, and that those who pass this ordeal satisfactorily will have the preference in all cases of trust and emergency, a great and a silent change for the better would speedily be effected in the management of

steam vessels and railway carriages, as well as in the practical construction of steam-engines. With such an institution properly managed, and such examinations well conducted, there would be no want of efficient officers to command and to conduct steam vessels of all kinds, or to organise and direct a steam fleet, should such a thing ever be required for national defence.

In composing this work, the author has had recourse to the most authentic sources of information. He has frequently cited the very words of the early historians of the steam-engine, as well as those of the original inventors, who have changed its form or added to its power. The works of Dr. Robison, Professor Millington, Mr. J. Scott Russell, and the original specifications and notes of James Watt himself, have either been consulted or employed in those chapters where the information they contain was of the greatest importance. Various other sources have been consulted, to which reference is made in the places where they are cited. For the original observations, which he hopes may be found of some advantage to the reader, the author must be considered responsible.

Dalston, January, 1852. R. W.

THE

HISTORY OF THE STEAM-ENGINE.

CHAPTER I.

STEAM, AND ITS EFFECTS, AS KNOWN TO THE ANCIENTS, BEFORE THE CHRISTIAN ERA.

All bodies in nature are presented to us in one or other of three different forms or states—viz., the solid, the liquid, and the gaseous. Most bodies can be made, by changes in temperature, to assume these different forms. The simplest and best known example is that of *water*. At the ordinary temperature of our climate, this is a perfect liquid; at a considerably lower temperature, it becomes solid, and is then called *ice;* at a very high temperature, it becomes gaseous, and is then called *steam*. A liquid, under the influence of heat, generates an *aeriform fluid;* this fluid, when free to expand in a given space, is called a *vapour;* but, when it completely fills that space, and prevents the farther vaporization of the liquid, it is called a *gas* or an *elastic fluid*. Although simple variations of temperature and volume will cause a gas to pass into the state of vapour, and conversely, yet the physical properties of the fluid, in these two states, are essentially different. Thus, by heating a given volume of air, or any other vapour, from 32° to 212° Fahrenheit, its elastic force is increased, on an average, only in the ratio of 1 to $1\frac{3}{8}$, or of 8 to 11, nearly; whereas, the elastic force of the vapour of water, while in contact with the generating liquid, between the same limits, is increased in the ratio of about 1 to 150. It is this enormous development of force, produced by the application of heat, which accomplishes in modern times, the amazing mechanical effects of *steam*, when employed as a *moving power*.

The ancients had no such clear notions of the nature of steam as those which have just been stated; although, in the writings of Plato, we find speculations concerning the nature and properties of the four elements, as they were called, fire, water, air, and earth, which show

that they were partially acquainted with the subject. It is true that only about a century and a half have elapsed, since steam began to be usefully employed as a moving power; and yet, the knowledge of its expansive force can be traced to a remote antiquity. This discovery must, indeed, have forced itself on the notice of those who first made use of a pot, with a lid to it, in culinary operations. It is, therefore, simply ridiculous to refer the discovery of the properties of *steam*, or the invention of the *Steam-engine*, to the Marquis of Worcester, who flourished in 1663, because he observed the lid of his tea-kettle thrown off by the force of the steam. For aught we know to the contrary, Adam and Eve may have witnessed such a phenomenon as this, in their post-paradisaical state.

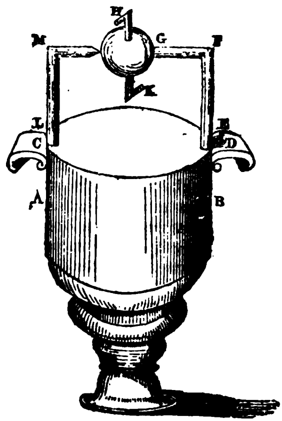
Hero of Alexandria, who flourished about 120 B.C., in a Treatise on *Pneumatics*, written in Greek, records the principal facts that were then known regarding the vapour of water, and gives an account of several machines in which the force of steam is employed to produce motion. One of these, the 45th in the book, consists of a pot with a lid, into which is fastened an upright tube, terminating in a perforated hemispherical cup, in which is placed a moveable ball. Water having been put into the pot, and the whole apparatus placed over a fire, as soon as the vapour or steam issues with sufficient force through the tube, it causes the ball to dance above the cup, with a rapidity varying according to the force of the steam. Fig. 1, is a representation of this apparatus, which is called in Greek *lebes*, that is, *pot* or *kettle*; it is taken from Commandine's edition of the work of Hero, published at Urbino in 1575, and has evidently been copied from the oldest MSS.

Fig. 1.

HERO'S STEAM-KETTLE AND BALL.

In this same treatise of *Hero*, there is a drawing and description of another Steam-machine, more ingenious than the preceding, and forming one of the various forms of an ancient apparatus called the *æolipile*, which is still used by lecturers on Natural Philosophy, to illustrate the nature and properties of steam. This machine, which is represented in Fig. 2, consists of a pot or vessel of water AB, placed over a fire as before, and covered with a lid CD, into which, at one side, is fixed the one end D, of a tube EFG, bent at right angles, and having its other end G, fitted into a hollow sphere, in the direction of its axis. At the other extremity of this axis, there is placed a pivot which is fixed on a rod LM, fastened to the lid, at the other side. From the sphere, two tubes H, and K, proceed in the direction of a diameter at right angles to the axis, and bent at right angles to this diameter, in opposite directions. When the vessel is heated, the steam will pass through the upright tube into the sphere, and thence issuing through the tubes bent at right angles, will cause the sphere to revolve with a velocity proportioned to the force of the steam. The representation of this apparatus is copied from an old edition of Hero's work, and, from its shape, it is evidently of great antiquity.

Fig. 2.



HERO'S REACTION MACHINE (*Æolipile*).

With respect to this machine, it may be observed, that if the steam were made to issue from straight tubes placed in the direction of the radii of the sphere, no motion would be produced; but, when these tubes are bent at right angles, the steam cannot issue from them without creating a certain *reaction* in a direction opposite to that from which the steam proceeds. This reaction produces a motion of rotation whose velocity increases in proportion to the intensity of the steam which issues from the tubes. The greatest effect is, of course, produced, when the orifices of the bent tubes are in opposite direc-

tions, and perpendicular to the same diameter. The issue of a liquid, under a sufficient pressure, will exhibit a similar phenomenon; and this is, in fact, the principle of the Hydraulic machine called *Barker's mill*. A similar result would arise from the issue of any gas; and two of the machines described in Hero's treatise, the 60th and 90th in the book, which are put in motion by heated air, are constructed on the same principle.

Whether the *æolipile* in the preceding forms, or in any other which it assumed in after times, was employed by the ancients for any practically useful purpose, cannot now be determined; but it is plain, that by attaching mechanism to the axis of the revolving sphere, some application might have been made of this machine. The principle has been repeatedly revived and employed by modern inventors, in what are called *rotary engines of simple emission*. It is even seen in the construction of rockets and fire-wheels; and in all cases, where fire, water, steam, or gas are generated in a close vessel, and then permitted to issue with violence; it drives the vessel from which it issues, in the opposite direction. The same principle is manifest in the recoil of a gun when fired, and in the simple emission of a fluid from a reservoir. Hence, if an apparatus be so arranged that water, steam, air, or gas be made to rush out of a close chamber through the arms of a revolving wheel, the apertures through which it escapes being properly directed, the recoil will cause the wheel to revolve, and the machine will constitute a rotary engine of simple emission. If, instead of employing the principle of recoil, the force of steam issuing from a fixed vessel, as seen in the case of the spout of a common tea-kettle, be directed on the vanes of a wheel so as to drive it round, this will form another species of rotary steam-engine with simple emission. The theory of such machines, in a variety of different forms, has been carefully investigated, and it has been found that in the most favourable circumstances, not more than half the power of the steam of the best rotary engines, can be made available for any useful mechanical effect. The celebrated Smeaton and others have subjected their operation to careful experiment, and the results obtained by the experimenters, are stated to be 3 parts out of 11; 8 out of 27; or 2 out of 5, as the greatest useful effect that could be attained in actual practice.

As patents have sometimes been taken out for air-engines in this country, it may be worth while to make a few remarks on one of those described by Hero, in his work above-mentioned. The apparatus may be called a *religious pantomime*, got up for the amusement and deception of the common people. A fire was kindled upon an altar to the gods, and animated figures were made to lead a choral dance in the interior of the altar, which was rendered visible by some transparent substance. Through the hearth, a tube was extended to the base of the altar, where it revolved on an iron pin, the other end being passed through a tubular fitting attached to the hearth. The tube had other cross tubes attached to it, and communicating with it, so as to radiate opposite to one another, and to have their ends turned in opposite directions. A drum was also attached to the tube, upon which the dancing figures were placed. The air, being heated

by the action of the fire, proceeded into the upright tube, and, being forced out through the radiating bent tubes, occasioned the former, with its drum to revolve, and produce the desired effect. Such an air-engine was only a philosophical toy, and never could produce any useful mechanical effect, owing to the want of force in the moving power. The same may be said of all air-engines, whatever may be the nature of their construction. They seem to act perfectly well in models made on a small scale and of light materials; but whenever they are tried on a large scale, and of a construction intended for practical purposes, they invariably fail, for want of actual power in the agent. Seeing, indeed, that common air, and all gases, expand only in the ratio of 8 to 11, when heated from the freezing to the boiling point, how is it possible that any air-engine can be effective when tried on a scale of sufficient magnitude to be a prime mover of machinery?

Another machine described by Hero, deserves to be mentioned here, not on account of the use to which it was put, which was only to aid superstition, but on account of its similarity in some respects to more modern inventions. This apparatus, which may be denominated the *Steam-oracle*, consisted of an altar with its fire lighted, and two figures of priests assisting in the sacrifices, with the figure of a dragon, (an appropriate symbol!) pretending to sibyllate, or foretel future events. On a hollow base was placed the altar, having a tube descending from it below the middle of the base, and there separating into three branches; one of these passed upwards in the interior of the dragon to its mouth; the other two passed upwards respectively in the interior of the other figures to the close covers of two vessels within them, containing wine, and in which they were fitted so as to be air-tight. In these wine vessels, were placed two syphons similarly fitted, having their shorter ends in the wine, and their longer ends in the hands of the figures which officiate at the sacrifices. A few drops of water being introduced into the tubes, the heat of the fire caused their vapour or steam to ascend in two of its branches to the wine-vessels, where, pressing on the wine, it was made to pass through the syphons and flow from the hands of the priestly figures, who thus appeared to sacrifice as long as the fire burned on the altar; the same heat caused the steam likewise to ascend in the third branch to the mouth of the dragon, and produce sounds which were ascribed to supernatural interference, and deemed oracular by the spectators. In this apparatus, we perceive the germ of the principle of raising of water by the pressure of steam, employed by Savery; and an anticipation of the method of producing sound by the steam-whistle used in locomotives on railways. There is, indeed, reason to suppose that to the knowledge of the elements of machinery, the ancients added some acquaintance with the power of steam. Pausanias compared the sounds emitted by the statue of Memnon to those produced by the snapping of harp-strings. Strabo states that he heard the same sounds; and Philostratus affirms that when the sun shone with full force on the statue, sounds issued from its mouth similar to those of a stringed instrument.

Vitruvius, the celebrated Roman architect, who flourished in the

reign of Augustus Cæsar, B.C. 27, speaks in his work, ***De Architectura***, of machines called *æolipiles*, in terms which show that he **was** acquainted with their principle of operation. He appears, however, to have been unacquainted with the difference between ***air*** and ***steam***; as he thought that ***water*** was converted into ***air*** by means of ***fire***. In attempting to explain the nature of winds, he assigns their origin to causes of the same kind as that which expels the ***air*** from an *æolipile*. ***Perrault***, the translator of Vitruvius, fell into the same error about seventeen centuries afterwards. In the Italian translation of his work, by ***Cæsar Cæsarino***, published at Como, in 1521, the *æolipiles* are represented by figures in the form of pots, kettles, and cauldrons, of various shapes, more or less elegant. Fig. 3, is an ingenious form of the *æolipile*, equipped with the modern improvement of the safety-valve. It consists of a small copper vessel of a globular form, *m*, having a tube, *t*, proceeding from the upper part of the vessel, and terminating in a very small orifice, *o*. Under it, is a spirit-lamp for boiling the water which the vessel contains. As soon as a sufficient quantity of steam is thus generated, it begins to issue from the orifice *o*, with the rushing noise and velocity of the wind. The vessel is supported by a frame, *p p*, which is mounted on wheels, *r r r*; so that when the steam issues from the orifice, the reaction occasioned by the resistance of the atmosphere, causes the whole machine to run in a direction opposite to that in which the steam proceeds from the vessel, as indicated by the point of the arrow. This apparatus is therefore a veritable steam-carriage in miniature.

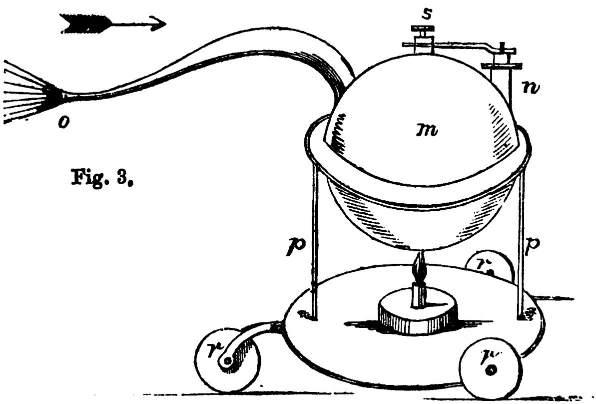


Fig. 3.

THE CABINET ÆOLIPILE.

The spring safety-valve, which is employed to prevent accidents, is represented at *n*, with its adjusting screw at *s*. In this form the

machine may be used as a blow-pipe or a pair of bellows. The name *æolipile*, which signifies *æolus' ball*, was not used by Hero, whose treatise contains the earliest account of this machine which has come down to us; but it is often used by subsequent writers, who appear to have had very erroneous ideas of the nature of its operation.

After the age of Hero of Alexandria, more than sixteen centuries intervene, which, with two or three trifling exceptions, appear to be wholly destitute of any historical traces, or authentic documents, relating to the nature of steam, or to its use as a moving power. After the reference already made to the work of Vitruvius, we only find the following notices which have reached us. *Seneca*, in the second century, attributed earthquakes to the violent operation of steam under the action of subterranean heat. *Anthemius of Tralles*, in the sixth century, according to the testimony of Agathias, a Byzantine historian, employed steam to shake the roof of a neighbour's house, whom he wished to terrify. It was only with the revival of literature, that the arts and sciences arose from their dreary sleep during the middle ages; and with them, the renewed investigation of the nature and properties of steam, and the consideration of its possible application to useful mechanical purposes.

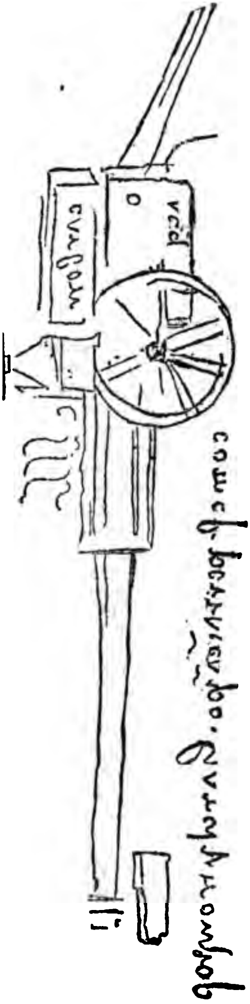
CHAPTER II.

STEAM AND ITS APPLICATIONS, FROM THE REVIVAL OF LITERATURE TO THE END OF THE SEVENTEENTH CENTURY.

As nothing contributed more to the revival of learning than the noble invention of the art of printing, so nothing was of greater advantage to its progress than the study of the works of the ancients, which were the first specimens of its production. Among these were editions and translations of the works of Hero, Archimedes, and other Greek writers on mechanics and natural philosophy; and in less than a century there were published eight or nine editions of the *Pneumatics* of Hero. It has lately been discovered that *Leonardo da Vinci*, the celebrated Italian painter, to whom the arts and sciences owed so much at this period, A.D. 1500, left some unpublished manuscripts, which have been preserved in the library of the Institute of France. These have been carefully examined by MM. Venturi, Libri, and others; and in particular by M. Delécluze, who has found in one marked B, the description and sketch of a *steam-gun*, denominated the *architonnerre*. Fig. 4 is an exact copy of this machine, taken from page 33 of the manuscript, and the following is a translation of its description:—"The architonnerre is a machine made of fine brass, which throws iron balls with great noise and much force. One-third of this instrument consists of a great quantity of fire and coal. When the water is properly heated, the screw on the vessel where the water is must be turned; and at the moment when the upper screw is turned, all the water will escape below, will descend into the heated part of the instrument, and will be immediately converted into steam so abundant and powerful, that the effects of its force and its noise will strike one with amazement. This machine will propel a ball weighing rather more than a talent."

This sketch shows the architonnerre mounted on wheels, having a box marked *carboni*, for *coals;* and a vessel, marked *acq.*, for *water*. Under the sketch are the words:—"*Come si porta in campo l'architonitro*," that is, "How the architonnerre is taken to the camp." The words marked on and under the figure are written, as in the original, from right to left, with the letters reversed; but they may be easily read by turning over the page, and holding it between the reader and the light. M. Delécluze says that *Leonardo da Vinci* ascribes the invention of this machine to *Archimedes*. The use of

Fig. 4.



STEAM GUN, REVIVED BY LEONARDO DA VINCI.

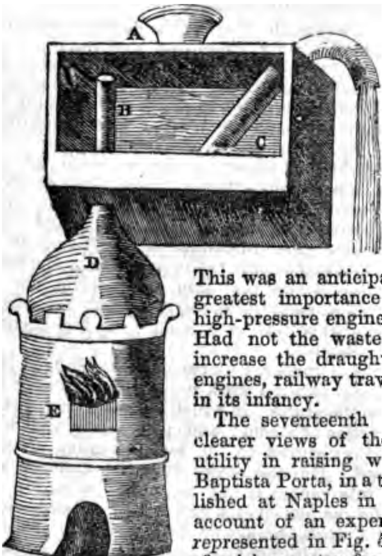
the word *talent* would seem to confirm his statement, this being the name of a Greek weight, varying in different states of Greece, from 60 lbs. to 120 lbs. in value; especially as Leonardo in his other writings uses the weights and measures of Italy. Among the works of Archimedes which have not reached our time, there is known to have been one on *Fires*. It is possible that the Italian philosopher may have obtained a knowledge of this work through the medium of some Arabic translation, in which he found the description of the *architonnerre*. It will remain a question for some oriental antiquarian to solve whether or not the *steam-gun* some years ago invented by Mr. Perkins, was not the veritable invention of *Archimedes*, thus brought to light by the writings of *Leonardo da Vinci*. May there not be some connection between the name of the engine and that of its inventor? In that case it will signify *Archimedes'-thunder*.

Plausible reasons, indeed, might be assigned for supposing that the Greeks had a knowledge of a machine analogous to the *steam-gun*. There appears to be some connection between the idea of the simple apparatus of Hero, represented in Fig. 1, and that of the architonnerre. If in the former, instead of allowing the steam to play like water upon the ball, it were allowed to accumulate till its pressure exceeded that of the atmosphere, and were then suddenly allowed to escape, the ball would instantly become a projectile rushing with proportionate violence through the air, and the machine itself a real steam-gun of the simplest construction. Moreover, it is well known that *Ctesebius*, the master of *Hero* in the Alexandrian school, had proposed to employ the elasticity of compressed air in a catapult of a peculiar construction; a fact fully confirmed by the description of the instrument itself (which was called the *ærotone*, or *air-driven*), given by *Philo*, of Byzantium. It was therefore as natural for the ancients to found the invention of the *steam-gun* on their know-

ledge of the expansive power of steam, as to found that of the *air-gun* on the known fact of the elasticity of the atmosphere. Nor is it improbable that the former was one of the inventions with which Archimedes was enabled to defend his native city, Syracuse, from the rude attacks of the enemy, and to resist for a period of three whole years the united force of the legions of Rome, and all the military skill of their famous general, Marcellus.

The sixteenth century witnessed several attempts at the introduction of steam as a moving power. *Blasco de Garay*, a Spanish sea-captain, is reported to have exhibited to the Emperor and King Charles V., in 1543, an engine by which ships could be propelled, without the use of oars and sails. The experiment was made at Barcelona, on the 17th of June of that year, on a vessel of 209 tons, called the *Trinity*, Peter de Scarza commander. The inventor never showed the construction of his engine to the public; but it was observed, at the period of the experiment, to consist of a large vessel of boiling water, and moveable wheels on each side of the ship. The speed attained was only three miles an hour. The account of this experiment was not published till 1826, long after steam navigation had been accomplished; of course it could have been of no avail to subsequent inventors, and has no claim to priority, earlier than the date of its publication. One *Mathesius*, the author of a volume of sermons entitled *Sarepta*, and published in 1563, indicates, in an obscure manner, the method of applying the force of steam to the raising of water from the mines of Joachimsthal, in Bohemia; and *Philibert Delorme*, in 1567, proposed to employ the *æolipile* for the purpose of increasing the draught of chimneys. This was an anticipation of a discovery of the greatest importance in the application of the high-pressure engine to locomotion on railways. Had not the waste steam been employed to increase the draught of the chimneys of such engines, railway travelling would have been yet in its infancy.

Fig. 5.



The seventeenth century commenced with clearer views of the nature of steam, and its utility in raising water to great heights. J. Baptista Porta, in a treatise on *Pneumatics*, published at Naples in 1601, gives the following account of an experiment with an apparatus, represented in Fig. 5, which exhibits a method of raising water from a reservoir, and also of

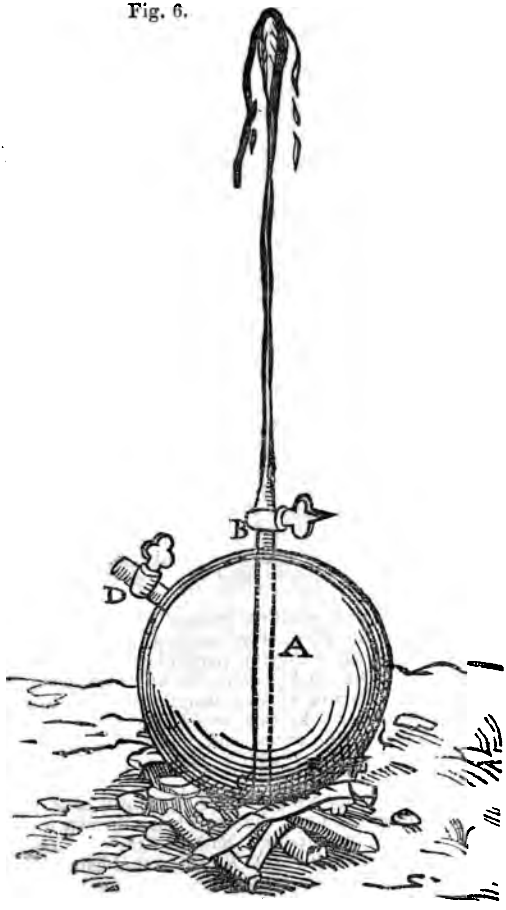
approximating to the solution of the question of the quantity of steam generated by a given quantity of water:—"Make," says he, "a box of glass or tin, A, having at the bottom an aperture, through which is inserted B, the neck of a distilling-flask, D, containing one or two ounces of water; and let its neck be cemented into the bottom of the box, so that there be no escape. Near the bottom of the box let there rise up a pipe, C, at such a distance from the bottom as to permit the water to escape; let this pipe pass through the cover, and rise a little way above its surface. The box is to be filled with water by an aperture, at A, which is to be well closed, so that no air may pass. Then place the flask, D, on the fire, E, and heating it slowly, the water it contains will be gradually dissolved into air [vapour], and press upon the water in the box; the force of this [steam] will next cause the water to issue through the pipe, C; and if the application of heat be continued, the whole of the water in the flask will be at last exhausted; and while this water is vaporising, the air [steam] will constantly press on the water in the box, forcing it to issue through the pipe in a continual stream. The exhalation [vaporisation] being finished, if you measure how much water is gone out of the box, that which is in the place of the water forced out, will give the measure of the remaining water. Thus you will find, from the quantity of water used, how much water was dissolved into so much air [steam]. And in like manner, also, you can measure into how much of more rarefied air, air of the ordinary density can be dissolved."

The knowledge obtained from the writings of the Greeks, and particularly the *Pneumatics* of Hero, is evidently applied and extended in this experiment; and although the method of determining the quantity of steam or aqueous vapour formed from a given quantity of water, is far from being perfect, owing to the condensation of the former, which would take place by coming in contact with the cold water in the box; yet the important fact, that the pressure of steam will raise water above its level and create a running stream, which might be employed for a useful purpose, is fully established. The principle exhibited in *Porta's* apparatus, must be considered as the germ of that part of Savery's engine, where the pressure of the steam is employed to force the water up the tube from the receiver into the cistern or reservoir. In this respect, therefore, it is vastly superior to a variety of later machines where steam was used as the agent, to produce new and amusing effects.

Solomon de Caus, a French engineer, who came to England, in 1612, to practise his profession, published a work under the imposing title of "*Les Raisons des Forces Mouvantes*," in which he shows an acquaintance with the chief properties of steam; and particularly that when it is condensed by cold, it is reduced to the same quantity of water which had been vaporised. He also states that the violence with which water is dissolved into vapour is so great, that if a strong ball of copper, containing water, be placed on a fire, it will certainly burst. In the fifth theorem of his work, he shows how water can be made by the application of fire to rise higher than its level. This apparatus is represented in Fig. 6. "Let there be a ball of copper A," says he

"well soldered all round, in which there is an aperture for putt water in, by means of a short tube and stop-cock at D. Another tube is closely fitted to the ball, having one end passing vertically down n the bottom, and the other above the ball, terminating in an orifice the emission of water, and also fitted with a stop-cock. Having nea

Fig. 6.



SOLOMON DE CAUS'S MACHINE.

filled the ball with water at D, let it be carefully stopped and put on a fire; then as soon as the heat acts upon the ball, with sufficient force, the water will rise in the tube BC, on the opening of the stop-cock at B." In the first theorem of the same work, when relating a similar experiment, the author states, that it is the force of the steam produced by the action of the fire from the water itself, which causes it to ascend with great violence, as soon as the stop-cock B, is opened. The limited nature of this apparatus renders it merely a philosophical toy, incapable of any practical application.

It appears that there was another writer of the same name and family, *Isaac de Caus*, of Dieppe, who published a work at London, in 1644, entitled "A New Invention for Raising Water Higher than its Source, with some Machines put in Motion by Water, and a Discourse on the Mode of Conveying the Same." This work contains an account of machines so very similar to those of Solomon de Caus, that the two persons have been considered identical.

Father Leurechon, a Jesuit of Lorraine, in his "*Mathematical Recreations*," published in 1624, under the assumed name of *Van Etten*, informs us that in his time, many persons amused themselves with turning little mills by the force of steam issuing from *æolipiles*. *Giovanni Branca*, an Italian engineer, published, in 1629, a treatise, entitled "*Le Machine*," in which the first application of steam-power to practical purposes, on a small scale, appears to have been effected. His apparatus consisted of an *æolipile* in the shape of a negro's head, having a pipe in his mouth, from which the steam issued, and exerted its force upon a wheel placed horizontally, and furnished with float boards or vanes like a water-wheel or wind-mill. This wheel produced a rotary motion, which by means of intermediate mechanism, gave a vertical motion to the stampers of a mill for pounding drugs and chemicals, and it was obviously applicable to various other useful purposes. This period, the infancy of modern mechanical inventions, teemed with engineering curiosities; such as perpetual motion, wings to enable men to fly in the air, self-moving chariots, conveyances to the moon, and engines for the production of continual music, the rocking of cradles, the turning of spits, and other automatic operations more ingenious than useful.

Father Kircher, in his work entitled *Magnes*, published at Rome, in 1641, describes a steam-machine, represented in Fig. 7, which differs from Caus's engine in the following particulars: the lower vessel which is placed over the fire, and contains the water for generating the steam, is furnished with a tube which transmits the steam to an upper vessel also containing water. In this vessel, the steam acts by its pressure on the surface of the water, and forces it out, by means of another tube, in a continued jet, with a force proportionate to that of the steam.

This machine is manifestly a copy of the apparatus of *J. B. Porta*, Fig. 5, but in a more elegant form, the water being thrown up in a jet, instead of being let down in a stream. Fathers *Schott* and *Dobrzenski*, two jesuits, probably pupils of *Father Kircher*, republished this apparatus or machine in 1657, merely as an amusing philosophical instrument, without any indication of its utility. Had the upper vessel

descending doth what nothing less than one hundred pound can effect.

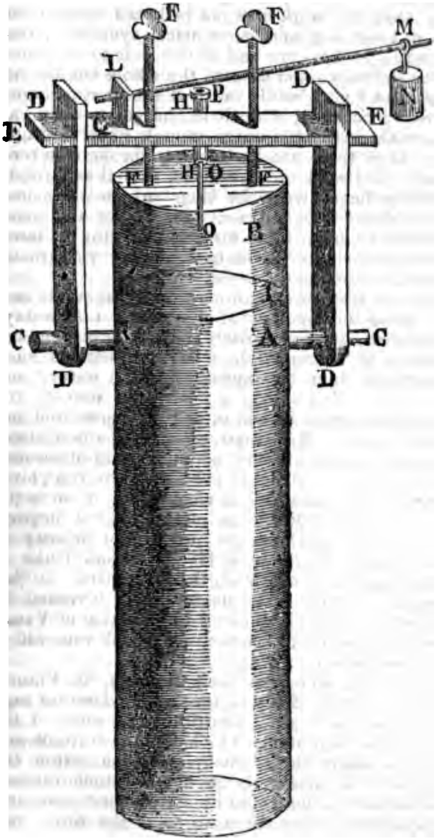
"Invention 100.—Upon so potent a help as these two last-mentioned inventions, a water-work is by many years' experience and labour, so advantageously by me contrived, that a child's force bringeth up, an hundred foot high, an incredible quantity of water, even two foot diameter, so naturally, that the work will not be heard even in the next room; and with so great ease and geometrical symmetry, that though it work day and night from one end of the year to the other, it will not require forty shillings reparation to the whole engine, nor hinder one day's work: and I may boldly call it the most stupendous work in the whole world; not only, with little charge, to drain all sorts of mines, and furnish cities with water, though never so high-seated; as well as to keep them sweet, running through several streets, and so performing the work of scavengers, as well as furnishing the inhabitants with sufficient water for their private occasions; but likewise supply the rivers with sufficient to maintain and make them portable from town to town, and for the bettering of lands all the way it runs, with many more advantageous, and yet greater effects of profit, admiration, and consequence."

In these curious extracts, from the Marquis's book, there is certainly a remarkably clear anticipation of the works now-a-days effected by the steam-engine, and particularly in the city of London; and it would almost seem to be impossible to have anticipated such wonderful effects, had he not been acquainted with the nature and operation of such an engine. Till within a few years, indeed, the evidence in his favour, as an inventor, was merely circumstantial and presumptive; but the labours of Mr. Stuart, one of our ablest historians of the steam-engine, have brought to light a manuscript account of the Marquis's own inventions, in which some controverted points have received considerable elucidation; and what is still more to the purpose, he has also discovered a document of the greatest importance, which appears at once to settle the question of priority of invention—namely, a "Diary of Cosmo de Medici, Grand Duke of Tuscany," who visited England in, or about, the year 1656. In this diary, the writer gives an account of the steam-engine invented by the Marquis of Worcester, which he had seen in operation at Vauxhall, for raising water from the river Thames, and which was said to be of more than two horse-power.

Denis Papin, M.D., F.R.S., who was born at Blois, in France, although not the actual inventor of the steam-engine, deserves high and honourable mention, as the original contributor of some of the most essential parts of that invention, which are in constant and daily use. These are the safety-valve, the cylinder and piston, the principle of the formation of a vacuum by the condensation of steam, and the production of motion in the piston by atmospheric pressure. In 1681, a book was published under the auspices of the Royal Society of London, written by Dr. Papin, which contained a number of curious and useful suggestions on various subjects—namely, cookery, sea-voyages, confectionery, making of drinks, chemistry, dyeing, and the propulsion of vessels by steam; with an account of the cost of a

good large engine, and the profit it would afford. Mr. Woodcroft, in his treatise on "Steam Navigation," published in the "Transactions of the Society of Arts for 1847-8," says that Papin was an improver and maker of steam-engines for pumping, that he proposed to apply them to the throwing of bombs; and, above all, to propelling a vessel against the wind. He also proposed to obtain a rotary motion from a reciprocating one, by employing two or three steam cylinders—the piston of the one to ascend, while that of the other was descending. A rack was to be attached to each piston-rod, capable of being taken into or withdrawn from a pinion on a paddle-wheel shaft, so that by alternately putting one rack into gear with the pinion and withdrawing the other, a rotary motion would be accomplished.

Fig. 8.



PAPIN'S SAFETY-VALVE.

The *safety-valve*, an apparatus so important in the management of steam-boilers, that, without it, they would every moment be liable to explosion, was first described by the inventor, Dr. Papin, in a small volume, entitled "*Traité très-curieux et utile pour amollir les os. Paris, 1682.*" This apparatus, which is represented in Fig. 8., was employed by him to measure the pressure of the steam in the culinary

vessel, still used, and known at the present day by the name of *Papin's digester.* Let A A be a strong iron vessel of this description, fitted with a top or cover, B B, to which is fastened an iron frame, C D, by means of screws, F F; this frame being fastened to the body of the vessel by the rod C C, passing through it at I I. The vessel A A, having been filled with water for the purpose of extracting the juices of bones of meat, or other useful purposes, is placed over a fire, or in a chemical water-bath.

For the purpose of ascertaining the quantity of pressure arising from the steam, the inventor took a small tube, H H, open at both ends, and having soldered it into a hole made in the lid B B, of the vessel A A, he applied, at the upper end of this tube, a small valve, P, exactly adjusted and fitted with paper; he then placed the iron rod, L M, in such a manner, that one end of it entered into the piece of iron, L Q, which was firmly fastened to the bar, E E; and the bar itself, resting upon the middle of the valve P, was prevented by the weight N, placed on the other end M, from being raised by the pressure of the steam generated in the vessel by the heat. The resistance of the rod to this pressure, as he remarks, is evidently greater or less, according as the weight N is placed nearer to, or farther from, the extremity M, just as in the common steel-yard. To promote the ready action of the valve, on the slightest indication of extra pressure, he inserted, within the tube H H, a small tube, O O, fitted with canvas, so that one of its extremities should always dip into the water contained in the vessel.

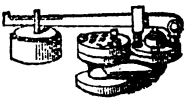
He made the tube H H, of small diameter, so that a great weight was not required to keep it shut. In a machine, which he placed in a water-bath, this tube was about two-fifths of an inch in diameter, so that its aperture was to that of a tube an inch in diameter, as 4 to 25; being therefore, about six times less in size, it could be kept shut with six times less weight. "Now," as he remarks, "according to the experiments of Boyle, the ordinary pressure of the air against an aperture of a foot in diameter is about twelve pounds, and, consequently, it is about *two pounds* against the aperture of my tube. The rod L M, in the machine, is about twelve inches long, and the distance from L, to the valve P, is an inch; so that having a weight of one pound at the extremity M, there will be as much pressure on the valve as if a weight of twelve pounds were directly applied to the aperture; so that this weight cannot be raised, if the pressure in the water-bath is not six times greater than the pressure of the atmosphere. Thus, when a weight of one pound is placed at the extremity M, and the valve P permits a little steam to escape, I conclude that the pressure in the water-bath, is about eight times greater than that of the atmosphere, since it can raise not only the weight which resists *six* pressures, but also the rod L M, which I know, by experiment, resists *two* pressures; and thus, by increasing or diminishing the weight, or changing its place, I can always ascertain, very nearly, how strong the pressure is in the machine or vessel."

In the preceding passage, Dr. Papin refers to the experiments of Mr. Boyle, who constructed the first accurate air-pump, by the assistance of Dr. Hooke, and published an account of his experi-

ments with that instrument in 1660. The first instrument of this kind, which was very imperfect, was invented by Otto Guericke, in 1654. The vacuum formed by the air-pump, in the experiments of Boyle, although not so perfect as that obtained in the celebrated experiment of Torricelli with the barometrical tube, in 1642, was still superior to that which had been hitherto accomplished by any other means; and it was universally denominated the *Boylean vacuum.* The experiments with the *Torricellian vacuum* proved that the atmospheric pressure varied from 14¾ lbs. to 15 lbs. on the square inch; but the experiments with the Boylean vacuum, owing to the imperfect exhaustion of the air-pump, would, of course, produce a less satisfactory result. Hence, we find Dr. Papin, in the above extract, stating the atmospheric pressure at only 12 lbs. on the square inch; but, as the French pound is heavier than the English pound, in the ratio of 13 to 12, the atmospheric pressure, even on this estimate, would amount to 13 lbs. on the square inch.

The utility of the lever safety-valve, as invented by Dr. Papin, has been much disputed; but it has been found so convenient in practice, that it is still retained. Various forms have been given to it, in order to render its indications more delicate, and its operation more safe. The form adopted by the French Academy at Paris, and by the Franklin Institute in America, consists of a lever balanced by two equal weights at unequal distances on opposite sides of the fulcrum, and pressing on the valve at a certain distance from the fulcrum. These weights rest on light rollers, which run down from their places, and entirely release the steam whenever its pressure reaches the limit of safety. The form and arrangement of the safety-valve in actual use is represented in Fig. 9. To the left of the valve, and in front of the lever, is placed a cover pierced with holes, which supports the fusible plate employed as an additional means of safety.

Fig. 9.



SAFETY-VALVE AND FUSIBLE PLATE.

In reference to these fusible plates or plugs, it may be remarked that their object is to prevent the explosion of steam-boilers. They are placed in the parts of a boiler exposed to high temperature or pressure, so as to form parts thereof; and they are formed of a composition of metals easily melted, so that they shall give way when, by accident or improper management, too great pressure and heat have been employed. The inadequacy of this plan has been proved by a committee of the Franklin Institute. It was found that alloys of tin, lead, and bismuth, of which the fusible plugs were composed, did not melt like a homogeneous metal, as it was supposed they would do; but that the more fusible metal melts in the minute cells of the less fusible metal long before the whole mass becomes liquid; that the harder metal forms a sort of grating or sponge in which the softer lies melted, so that when the steam rises to melt the first metal its pressure gradually expels the melted metal out of the meshes of the unmelted, in globules, so that the plate consists at last of the latter *only.* The minute cells of this metal are filled up by *other infusible* substances, and a plate consisting of two metals,

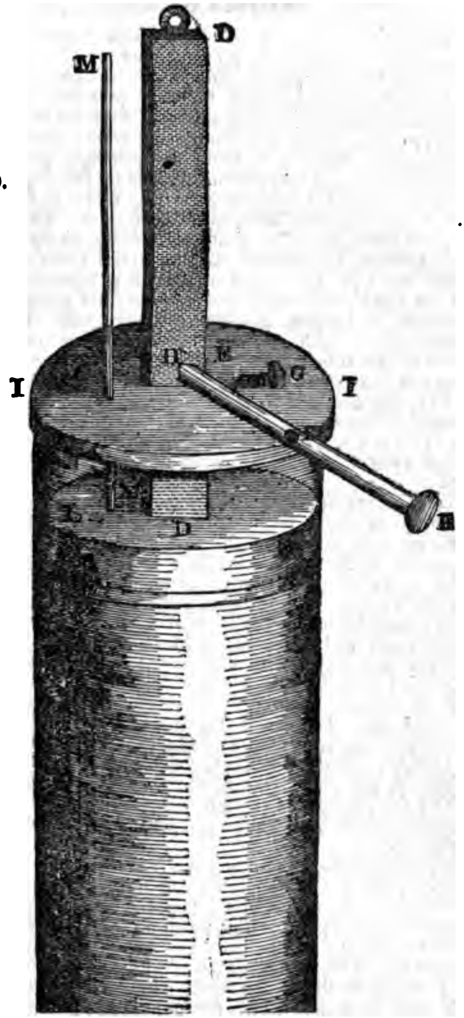
originally intended to melt at 250 deg., under a pressure of two atmospheres, may still deceive the engineer, and will hold its warning until it has reached a temperature of 500 deg., under a pressure of 45 atmospheres, when the high-pressure steam of the boiler may cause it suddenly to explode with the force of gunpowder.

The invention of a steam-machine or apparatus, consisting of a cylinder and piston, which now forms the principal part of all our modern steam-engines, is unquestionably due to Dr. Papin, and we do not much wonder at his countrymen setting up his claims as superior at least to those of the Marquis of Worcester. Of the engine invented by the latter, no trace whatever remains, except the fact of its existence asserted by himself and the Grand Duke of Tuscany. Of the former we have the following drawing, represented in Fig. 10, and the description written by the inventor, and published in the *Acta Eruditorum*, at Leipzig, in 1690. "AA is a tube of equal diameter throughout its length, and closed at the bottom; BB is a piston exactly fitted to this tube; DD is the handle attached to the piston; EE is an iron rod, turning on an axis at F; G a spring which presses the iron rod EE, and makes it enter the notch H, as soon as the piston, with its handle, is raised high enough to show the notch above the lid or cover II; L is a small hole in the piston, through which the air in the tube AA escapes, when the piston descends to the bottom for the first time.

"In using this instrument, a little water is poured into the tube AA, to the depth of about three-tenths of an inch. The piston is then introduced, and pushed to the bottom, so that the water in it begins to run out at the hole L; the hole is then closed by the rod MM, and the cover II, pierced with as many holes as possible, is placed over the whole. A fire is then put under the tube AA, which will heat very quickly, because it is constructed of thin metal; and as soon as the water within is converted into steam, it will create a pressure so great as to exceed the weight of the atmosphere, and push the piston BB upwards, till the notch H appears above the cover II, and the rod EE is pushed into it by the spring G, an effect not produced without noise. The fire is then immediately withdrawn, the steam is speedily condensed into water by the cold, and a vacuum is formed in the tube. The rod EE is then turned on its axis, to free it from the notch H, and permit the piston to descend, which it will instantly do by the pressure of the atmosphere. In this way motion will be produced as often as you please, with a force increasing with the size of the tube."

"There is no doubt that the air will act in the tube with the whole force of gravity; for it has been observed by experiments, that the piston, after having been raised by the heat to the top of the tube AA, has descended to the very bottom many times in succession; so that there cannot be any air in the tube to support it from below, and resist its descent. Now, a tube which is only 2½ inches in diameter is capable of raising 60 lbs. to the whole height from which the piston descends, and its weight is only five ounces. It is evident, therefore, that tubes might be made which weigh no more than 40 lbs., and which could raise 2,000 lbs. to the height of four feet at each

Fig. 10.



PAPIN'S STEAM CYLINDER AND PISTON.

operation. It has been proved also that *a minute* is sufficient to enable a moderate fire to drive the piston to the top of the tube; and, as the fire must be proportioned to the size of the tubes, the large tubes can be heated nearly as easily as the small ones; hence, this simple machine is capable of producing enormous forces at a rapid speed. Now, a column of air, which rests on a tube a foot in diameter, weighs nearly 2,000 lbs.; but if the diameter were two feet, the weight would be nearly 8,000 lbs., as the pressure always increases in the duplicate ratio of the diameters. Whence it follows that the fire, in a furnace whose diameter is a little more than two feet, would be sufficient to raise every minute 8,000 lbs. to the height of four feet, if the tubes were made of this height; and the fire being placed in a furnace of thick iron plates, it could be easily pushed from one tube to another; so that the same fire would continually form in one of the tubes the vacuum which is capable of producing such great effects. It would take too long to mention here how this invention might be applied to mining, military, nautical, and other purposes; but every one can most readily adapt it to the wants of his own profession. The chief difficulty would be the construction of proper tubes, as stated in the *Acta Eruditorum* for 1688." There can be no doubt that the grand principle by which the moving power is made to operate in all our modern steam-engines was fully developed by Dr. Papin, in the machine just described in his own words; and although he did not construct a steam-engine until he had seen a drawing and description of a later invention by a cotemporary, yet the improvements which he made in this engine, coupled with his own original inventions, paved the way for all subsequent inventors. The discovery of the method of forming a vacuum by the condensation of steam, and of producing motion in the piston by atmospheric pressure, is unquestionably due to Dr. Papin.

Thomas Savery, Gent., otherwise called Captain Savery, obtained a patent, in 1698, for "raising of water, and occasioning motion to all sorts of mill-works, by the impelling force of fire," which he stated would be "of great use for draining mines, serving towns with water, and for the working of all sorts of mills, where they have not the benefit of water or constant winds." The inventor exhibited a working model of this machine to the Royal Society of London in 1699. We agree with Mr. Scott Russell in his account of this engine, when comparing the merits of Captain Savery's invention with those of the Marquis of Worcester. "We have seen," says he, "that the Marquis's model appears to have been placed on or below the level of the water to be raised, and that his vessels being filled, their contents were raised by the elastic force only of the steam. Mr. Savery, on the other hand, erected his engine at a height of nearly thirty feet above the level of the water. A large close vessel was filled with steam; this steam was reconverted, by cooling the outside of the vessel, into water, leaving the large space it had formerly occupied vacuous. Into this vacuum water was raised, as into the vacuum of a common sucking-pump, by atmospheric pressure, and so, within the limit of atmospheric pressure, raised twenty-eight or thirty feet. *After this was* accomplished, the water was further raised by the

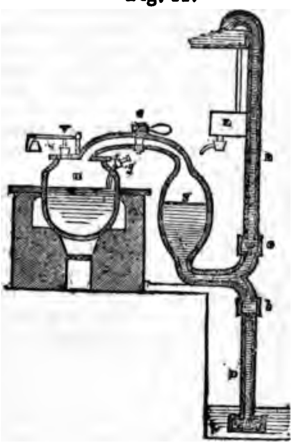
elastic force of the steam, just as in the [supposed] engine of the Marquis of Worcester. But the improvement was great. The same force of steam, strength of vessels, and consumption of fuel, which were sufficient, on the Marquis's plan, to raise water thirty feet, would be capable of drawing up the water thirty feet, and then thirty more, on Savery's plan, or doing double the work, or sixty feet of height. This was certainly a notable improvement." In continuing this comparison, he justly remarks that their claims rest on independent grounds. The Marquis of Worcester expressly disclaims the use of a vacuum, a thing which is the distinguishing feature of Captain Savery's; for he says, "not by drawing it or sucking it upwards, for that must be, as the philosopher calleth it, '*intra sphæram activitatis,*' which is, *but at such a distance*: but this way [by high pressure] hath no bounder, if the vessels be strong enough." The Marquis here uses the language of the schools when, speaking of the limits of a vacuum in the use of common pumps, he says, "*within the sphere of activity*"—that is, within the limits of a certain distance, namely, 33 feet. Captain Savery on the other hand, added the principle of high-pressure to the principle of forming a vacuum by condensation, the former having been known before the Christian era, but the latter only from the time of Dr. Papin. The Captain, however, appears to have been the first inventor of the principle of condensation, by throwing *a jet of cold water* on the vessel which contained the steam. This also was a notable improvement on that of Dr. Papin, and one which more than doubled its utility in practice.

In the sketch or drawing of the Marquis of Worcester's supposed steam-engine given by Professor Millington, already referred to, he says that the inventor speaks only of the expansive force of steam, without alluding to its condensibility, although this has been taken into account in its explanation; and adds that the condensation of steam affords no other assistance to that machine than by filling the vessels with the water to be raised, and that, consequently, the whole effort of raising the water into the cistern must depend upon the expansive force of the steam employed. Again, from these vessels being constantly under water, they will be kept in a very cold state, and all the first portion of steam that enters them must be condensed and lost, instead of being permitted to exert its expansive force, and a very considerable quantity of steam must be dissipated in this way; so, also, the fuel employed to produce that steam must be wasted. In Savery's engine these inconveniences did not exist; for, instead of throwing the whole burden of raising the water upon the force of the steam, he raised it, as far as atmospheric pressure would permit, by a vacuum produced, as we have remarked, by the condensation of steam, and then effected the remainder of the lift by its expansive force.

Having thus explained the principle of Captain Savery's engine, it may be proper now to give a description and representation of his first engine, similar to that which he actually erected at Camden House, an account of which was given by Mr. Bradley, in his "Treatise on Gardening. In Fig. 11, B, the boiler, is a strong copper vessel, with its fire-place, set in brickwork. From this vessel, in

which the steam is generated, a steam-pipe, furnished with a stop-cock or regulator at C, passes into an air-tight copper steam-vessel or receiver at S. This vessel, at first setting to work, is full of air, which the steam is made to discharge through the clack-valve at *a*, whence it ascends into the force-pipe A. After the receiver S is thus freed from air, which is ascertained by its being hot with steam, the steam-regulator C is shut, and cold water is thrown upon the outside of the receiver; this cools the steam inside, and causes it to condense, leaving a vacuum in the receiver, into which the pressure of the atmosphere, acting on the surface of the water to be raised, forces a column of water up through the suction-pipe *p*, and the clack-valve *b*, from the pond, well, or pit containing the water.

Fig. 11.



SAVERY'S FIRST STEAM-ENGINE.

As soon as the receiver S is thus filled with water, the stop-cock C is opened, and the steam passes from the boiler B into the receiver; this steam presses on the surface of the water it contains, and forces the water through the clack-valve *a* up the force-pipe A; this force being expended, the weight of water in A shuts the valve *a*, and prevents its return to the receiver S, or to the suction-pipe *p*, in which the valve *b* is made to shut by the pressure of the water in the part of the tube communicating with the receiver S. When the receiver is thus emptied into the force-pipe A, which is easily perceived by the receiver becoming hot with the steam, the regulator or steam-cock C is shut; the steam in the receiver is condensed by opening the cock of the small reservoir E, which contains cold water admitted either from the force-pipe A, or the cistern at its top, which receives the water thrown up. As soon as the steam is condensed in the receiver S, the water in the well or pit will immediately ascend through the suction pipe *p* and the valve *b*, and replenish the receiver S as before. The steam-cock C being now opened, the steam is admitted into the receiver S, presses on the surface of the water in it, and forces the water up the pipe A, as before, into the cistern placed at the top. The steam-cock C is then shut, and the cock of the reservoir E is opened; by the condensation, the steam-vessel S is refilled with water, and forced up the pipe A as before; and it is evident that this process may be continued for any length of time that may be required.

There can be no doubt that the form of Savery's first steam-engine now described, was taken directly from that of a common lift-and-force-pump, the action of steam being substituted for that of the pump-

piston. In Fig. 11, the suction-pipe *p*, and the force-pipe A, form but parts of one and the same machine. The receiver or steam-vessel S takes the place of the cylindric chamber of the force-pump with its piston; the clack-valves A and B are the same in both machines; the filling of the receiver with steam, and its pressure on the surface of the water, is the substitute for the forcing down of the close piston in the cylinder, to drive the water up through the clack-valve *a* and the pipe A; and the condensing of the steam in the receiver to create a vacuum, is the substitute for lifting the same piston up to form a vacuum, for the admission of the water through the clack-valve *b*, and the suction-pipe *p*. The boiler B is furnished with a safety-valve V, to prevent accidents, and to regulate the pressure of the steam in the receiver. It is also furnished with a gauge-cock *g*, to ascertain the depth of the water in the boiler B. The utility of the safety-valve for ascertaining the pressure of the steam is obvious; for if the height of the force-pipe A is about 30 feet, the column of water in it is equal to the pressure of one atmosphere, the steam in the receiver S must then be equal to that of two atmospheres, in order to raise it into the cistern; and consequently equal to that of more than two atmospheres, in proportion as the height of the pipe exceeds that of thirty feet.

Captain Savery continued to make improvements upon his single receiver engine, according as it came into useful and practical operation. One of the most important of these was the substitution of a pipe communicating with the receiver S, and the force-pipe A, and furnished with a cock, called the *injection cock*, instead of the reservoir E with its cock, for condensing the steam. The mouth of this injection-pipe had a nozzle pierced with small holes radiating in every direction, and condensing the steam in the interior of the vessel, more rapidly than when the water was applied outside, and without cooling the receiver S, to such an enormous degree as formerly. His next improvement was the invention of the *trial* or *gauge cocks*, already alluded to, for the purpose of ascertaining when the boiler contained its proper quantity of water; these are of no small importance, and are carefully retained in all modern engines. A pair are generally placed in the upper part of the boiler, and pipes proceed from them down into the interior. In explaining their use, it may be advisable to remark that all steam-boilers, and particularly those intended for the use of steam-engines, should be so large, that the quantity of water required for use should not near fill them; but that a great space should be left above the water, to act as a reservoir or receptacle for the steam as it is generated. Unless this were done, the cylinder or vessel to be filled with working steam might contain more than the space which existed above the water, and consequently could not be supplied with steam regularly, or with the necessary degree of speed. On the other hand, if the upper part of the boiler should contain a volume of steam ready for action and considerably greater than what the cylinder or vessel can contain, the latter can always be supplied without materially diminishing the force or density of what remains in the boiler, and the speed of the engine will therefore be maintained; while, if this were not the case, the speed must be slackened

or suspended altogether, until the continued action of the fire generated the necessary quantity of steam. It is therefore important that the water in a boiler should never rise much beyond some settled height; and it is equally unnecessary that the boiler should contain a sufficient quantity of water to enable it to produce the steam required, and to protect it from the action of the fire. These precautions are necessary to prevent not only inconvenience in the working of a steam-engine, but danger which might arise from the explosion of the boiler itself. For, whenever a part of the metal which is exposed to the action of the fire ceases to be covered with water, it is then liable to be *burnt*—that is, to become *red hot*. It then decomposes, and soon wears into a hole, when explosion becomes inevitable.

When the *gauge-cocks* are properly attended to, they will at all times indicate the height of the water within the boiler, while a fire is underneath it, with sufficient accuracy to prevent accidents. They are made of brass, and are screwed into their places in the upper part of the boiler, so as to be perfectly air or steam tight. They are united to pipes which pass down into the inside of the boiler, the one pipe being shorter than the other by a quantity varying from four to six inches, their entire length being fixed by the water-line of the boiler, which must be previously determined. Then the shorter gauge-pipe should extend to within two or three inches of this line, and the longer gauge-pipe to about two or three inches below it, that is, dipping so much into the water. Accordingly, when the cock of the longer pipe is opened, boiling water should issue from it, but no steam; and when the cock of the shorter pipe is opened, steam only should issue from it, and no water. This will always be the case when the boiler is filled with water to its proper height, and will show that the surface of the water is somewhere between the extremities of the two pipes. If the boiler be too full of water, then its surface will be above the extremity of the shorter pipe, and water will issue from both cocks when opened; but if the water be too low in the boiler—that is, below the extremity of the longer pipe, steam will issue from both cocks when opened. To each of these cases the proper remedy must be applied; but while steam issues from the one cock and water from the other, the boiler may be considered as containing its proper charge of water, and may continue to be worked with safety and advantage. The management of the surplus or deficiency of a boiler is provided for by an apparatus which will be described in another chapter.

In concluding this account of Captain Savery's first steam-engine, it may be worth while just to advert to some of its defects which he tried to remedy, and which led to the invention of another machine, in which he had at least a monetary share. As the water is elevated in the force-pipe by the elasticity of the steam, this must, in the boiler and every part of the machine, be such as to exert a pressure on every square inch of the vessels equal to that of the upright column of water in the pipe. Now, in order to raise the water into a reservoir 100 feet high above the level of the well or pit in which it is contained, a pressure of nearly three atmospheres would be re-

quired, or a supply of high-pressure steam of the temperature of 275 deg. Fahrenheit. Of the 100 feet, about a fourth part may be accomplished by raising the water in the suction-pipe to the receiver, and the remainder, or 75 feet, must be effected by forcing it up the pipe by the pressure of the steam alone. For this moderate height, very strong vessels would be required—a fact of which even the Marquis of Worcester seems to have been well aware, when he speaks of a way to make his vessels so as to be strengthened by the force within them; for from these words, it would appear that he had overcome the difficulty of making steam-tight joints by using internal flanges, which should become tightened by the internal pressure of the steam. At such a heat as that above-mentioned, soft solder is weak, and spelter solder, or strong rivetting, ought only to be used. The necessity of this was rendered strikingly evident by an accident in a machine erected by Captain Savery. The workman having loaded the safety-valve a little more than usual, to make the engine work briskly, the boiler burst with a dreadful explosion, killed the workman, and blew up the furnace and adjoining parts of the building, as if it had been filled with gunpowder. Mr. Savery succeeded pretty well in raising moderate quantities of water to small heights, but he could make nothing of deep mines. Many attempts were made, on the supposed principle of the Marquis of Worcester, to strengthen the vessels from within by radiated bars, and from without by hoops, but the results were invariably unsatisfactory. Trials were also made with very small boilers or vaporisers, kept red-hot, or, at least, to a very high degree of heat, and supplied with a small stream of water, which was allowed to trickle into them; but they failed in producing a sufficient collection of steam during the cooling of the receiver, in readiness for the next forcing operation; hence, the working of such engines was always an employment of great danger and anxiety to the attendants.

CHAPTER III.

PROGRESS OF THE STEAM-ENGINE FROM THE END OF THE SEVENTEENTH CENTURY TO THE ERA OF WATT.

The beginning of the eighteenth century was signalised in the history of the steam-engine, by arduous and successful attempts to render it useful in the draining of mines—a branch of industry so essential to the prosperity and wealth of this country. Captain Savery had made very great improvements upon his engine, insomuch that it assumed a new form, much more adapted to effective practice than the former (as described in the preceding chapter), and capable of being erected on a large and expensive scale. The chief defect of the first form of his engine was its intermittent nature, which rendered it incapable of keeping up a continued flow into the cistern, whereby both loss of time and waste of fuel were occasioned to a very considerable extent. An account of his second, or improved engine, which was invented to obviate this defect, was published by himself, in a small work called the "Miners' Friend," London, 1701. It was extensively applied to draw water from deep mines, being placed under ground, on a platform, from twenty to thirty feet above the level of the water, and the chimney ascending in the shaft of the mine, along with a pipe, through which the water was forced to the surface. The form and principle of the second engine was, of course, exactly similar to those of the first, the chief difference consisting in the use of two receivers—like s., in Fig. 11—instead of one. These communicated by separate pipes with the same boiler, and had their respective clack-valves in separate pipes, which divaricated from the same suction-pipes, and united again in the same force-pipe; so that, while the one receiver was discharging its water, the other was forming a vacuum, and drawing up its charge of water from the pit. By the adoption of a second, or subsidiary boiler, the inventor, ingeniously compensated for the reduction in the quantity of water, arising from constant vaporization in the main or principal boiler, without having occasion to stop the machine in order to replenish it with water. This was effected by placing a small boiler by the side of the larger one, and shutting them up close from communication with the external air. A pipe, fitted with a cock, passed up from near the bottom of the smaller boiler to the upper part of the larger one; and, when the steam was produced in the smaller boiler, and pressed

within it on the surface of its own generating water, as soon as the cock in this pipe was opened, all this water was driven through it, in a boiling state, into the larger boiler. This cock was then shut, and the small boiler was replenished with cold water through a pipe leading from the force-pipe. This cold water, of course, remained in the small boiler till it was again raised to the boiling state abovementioned, when it was discharged into the larger boiler, as before. By this means, the heat of the water in the large boiler was never checked by the introduction of cold water. This important principle of management is most scrupulously attended to even in the construction of the improved engines of the present day. The time for opening and shutting the cocks was always indicated by the rattling of the clack-valves; and the labour of turning them, and tending the fire, was no more than a boy could perform during a whole day.

Having thus given an account of Captain Savery's steam-engine, both in its original state and in its most improved form, we might now pass to the consideration of the improvements subsequently effected by other inventors. But in a history of the steam-engine, some notice must be taken of the various opinions which have been transmitted to us, regarding the merits and originality of the different inventors. Among the writers belonging to the epoch under discussion, Dr. Desaguliers, a man of considerable reputation as a philosopher and mechanist, has given the following story, in vol. ii. of his *Experimental Philosophy*:—London, 1734. "Captain Savery having read the Marquis of Worcester's book, was the first who put in practice the raising of water by fire, which he proposed for the draining of mines. His engine is described in *Harris's Lexicon*, which being compared with the Marquis of Worcester's description, will easily appear to have been taken from him, though Captain Savery denied it; and the better to conceal the matter, he bought up all the Marquis of Worcester's books that he could procure, and burned them. He said that he found out the power of steam by chance; that having drank a flask of Florence, and thrown the empty flask upon the fire, he called for a basin of water to wash his hands; and perceiving that the little wine he left in the flask had filled up the flask with steam, he took the flask by the neck and plunged the mouth of it under the surface of the water in the basin, and this water was immediately driven up into the flask by the pressure of the air. Now, that he never made such an experiment, I thus prove: I made the experiment purposely with about half a glass of wine left in the flask, which I laid upon the fire, till it boiled into steam; then putting on a thick glove, to keep the neck of the flask from burning me, I plunged the mouth of the flask under the water that filled the basin; but the pressure of the atmosphere was so strong, that it beat the flask out of my hand with violence, and threw it up to the ceiling. As this must also have happened to Captain Savery, if ever he had made the experiment, he would not have failed to tell such a remarkable incident, in order to embellish his story."

Strange as the preceding account must appear to the candid reader, the following comment on it, written by Mr. J. Scott Russell, will *appear stranger* still. "We have," says he, "performed the Doctor's

experiment frequently, with various results. If the mouth of the flask happens to be large and its neck short, the water very cold, and the flask perfectly filled with steam, the effect is exactly what Desaguliers describes; for the vacuum being suddenly and completely formed, the flask is first pressed down towards the basin, which the hand resists by sustaining the flask in the opposite direction, and just then the water rushes with great velocity into the vacuum, and striking on the bottom of the flask now turned upwards, is apt to knock it suddenly out of the hand. But if, on the other hand, the flask has a narrow mouth and a long neck, and if when inverted, its neck be allowed to rest on the bottom of the vessel, and if the water in the basin be not very cold, it will rise slowly and gently, and the flask will be completely filled. The Doctor's inference is not, therefore, perfectly just to Savery, who, if he had read Worcester's book, would not find in it any such principles, but an express exception from it."

The true solution of the Captain's experiment, as narrated by Dr. Desaguliers, is simply this: the quantity of steam arising from the *very small quantity* of wine left in the flask, which could not be above two or three drops, was not alone sufficient to fill the flask; it was consequently mixed therein with the atmospheric air, which always renders steam visible; into this mixture, the water of the basin would immediately rise, by the condensation of the steam; but its violent pressure, arising from sudden condensation, would be instantly checked by the resistance of the atmospheric air of the mixture, which would not condense like the steam; and thus the effect experienced by Dr. Desaguliers and Mr. Russell would not be felt. Both these experimenters appear evidently to have put as much wine into the flask, as would generate enough of steam to fill the flask, and expel the atmospheric air; whereas, Captain Savery left only a small quantity, quite insufficient for this purpose; hence, the reason of the difference in the results. Nothing conclusive, therefore, against the independent claims of Savery to the real discovery of the principles of condensation, employed in the steam-engine, can be gathered from this story of Dr. Desaguliers.

A very different account of Captain Savery's "engine for raising water by fire" is given by Stephen Switzer, a contemporary author, in his "System of Hydrostatics and Hydraulics," published at London in 1729. "Amongst the several engines," says he, "which have been contrived for the raising of water for the supply of houses and gardens, none has been more justly surprising than that for the raising of water by fire, the particular contrivance and sole invention of a gentlemen with whom I had the honour, long since, to be well acquainted—I mean the ingenious Captain Savery. This gentleman's thoughts were always employed in hydrostatics, or hydraulics, or in the improvement of waterworks: and the first hint from which, *it is said*, he took his engine, was from a tobacco-pipe, which he immersed in water to cool it. He discovered that the water *was made to spring* through the tube of the pipe in a wonderful and *surprising manner; though* others say that the learned Marquis of *Worcester, in his* 'Century of Inventions' (which I have not seen),

gave the first hint for the raising of water by fire. It was a considerable time before this curious person, who has been so great an honour to his country, could bring his design to perfection, on account of the awkwardness of the workmen who were necessarily to be employed in the affair; but at last he conquered all difficulties, and procured a recommendation of it from the Royal Society ('Philosophical Transactions,' 252), and soon after a patent from the Crown; and I have heard him say myself that the very first time he played it was in a potter's house at Lambeth, where, though it was a small engine, yet the water forced its way through the roof, and struck up the tiles in a manner that surprised all the spectators."

The preceding account of this invention is much more likely to be the true one than that given by Desaguliers; and we cannot conclude the subject more appropriately than by citing Dr. Robison's remarks, in his account of the steam-engine:—"Captain Savery, a person of great ingenuity and ardent mind, saw the reality and practicability of the Marquis of Worcester's project. He knew the great expansive power of steam, and had discovered the inconceivable rapidity with which it is reconverted into water by cold; and he soon contrived a machine for raising water, in which both these properties were employed. He says that it was entirely his own invention. Dr. Desaguliers insists that he only copied the marquis's invention, and charges him with gross plagiarism, and with having bought up and burned the copies of the marquis's book, in order to secure the honour of the discovery to himself. This is a very grievous charge, and should have been substantiated by very distinct evidence. Desaguliers produces none such, and he was much too late to know what happened at that time. The argument which he gives is a very foolish one, and it gave him no title to consider Savery's experiment as a falsehood; for it might have happened precisely as Savery relates, and not as it happened to Desaguliers. The fact is, that Savery obtained his patent of invention after a hearing of objections,* among which the discovery of the Marquis of Worcester was not mentioned; and it is certain that the account given in the "Century of Inventions" could instruct no person, who was not sufficiently acquainted with the properties of steam, to be able to invent the machine himself." To those who know the history of Dr. Robison, and his practical and theoretical skill, both as a mechanician and a philosopher, this summary of evidence in favour of Captain Savery will appear both conclusive and satisfactory.

That the invention of a machine promising such great advantages as were to be expected from the steam-engine, even in its infancy, should have been claimed by several individuals, is not to be wondered at. Accordingly we find that, notwithstanding its well-defined commencement above detailed, most of the French writers appropriate the invention to their own nation, and particularly to *Amontons* or *Papin*. These ingenious persons, indeed, did propose or construct machines to operate by the agency of fire; but the invention of

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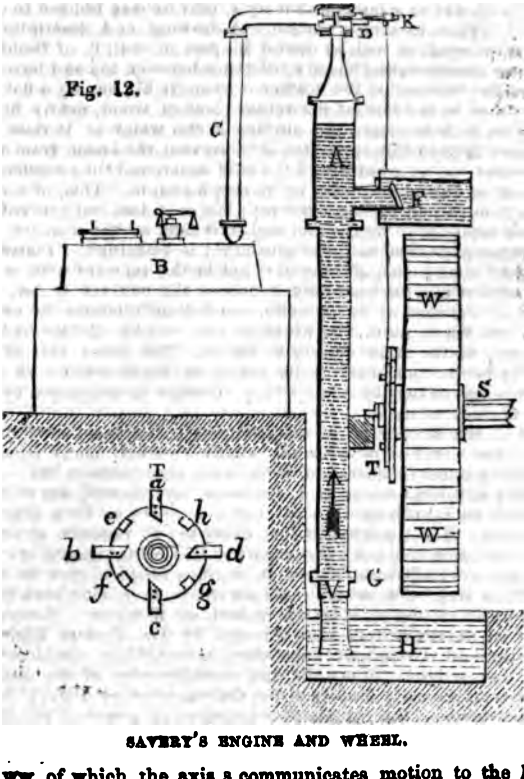
* And, as Dr. Robison observes, "after having actually erected several *machines*."

Amontons, which is fully described under the name of a *Fire-mill* in the "Memoirs of the Academy of Sciences" at Paris, for 1699, will be found to bear no resemblance in any part to a steam-engine; while that of Papin is a most palpable copy of Savery's engine. In fact, all his first attempts to obtain a working-engine proved abortive, although carried on at considerable expense under the auspices of the Landgrave of Hesse; and it was not until 1707, or nine years after the date of Savery's patent, that he was enabled to produce an engine, which was so similar to Savery's, that he was obliged to confess his obligation to that invention. A drawing and description of Papin's steam-engine will be found in part ii., vol. ii. of Belidor's *Architecture Hydraulique*, the only difference between his and Savery's being that the receiver in the former is cylindrical, having a flat top and bottom, so as to admit of a circular piece of wood, nearly fitting the cylinder, to float upon the surface of the water as it rises and falls. The object of this apparatus is to prevent the steam from coming in contact with the surface of the cold water, and thus condensing to such a great degree as it does in Savery's engine. This, of course, is, to a certain extent, an improvement; but as it does not prevent the condensation produced by the wet and cold sides of the receiver, it is of less importance than at first sight might be imagined. Instead of employing the suction-pipe, Papin supplies the receiver with water by mere hydrostatic pressure; for he places the receiver so low, that the water runs into it by its own effort, and thus obviates the necessity of a perfect vacuum, and prevents the cooling of the receiver to the same extent as in Savery's engine. The latter part of the scheme, however, can scarcely be called an improvement, as it is evidently a return to the plan either adopted or suggested by the Marquis of Worcester.

Owing to the simplicity of construction in engines on Captain Savery's plan, especially with the single receiver, many attempts were made to improve them, and bring them into common use. One of the first applications, indeed, proposed by himself, was to raise water to fall on a mill-wheel, and turn machinery as by a common fall of water. The quantity of fuel necessary to produce steam of high temperature, and the greater part of this being wasted at every stroke, are the chief causes why such engines failed to give satisfaction; yet for small lifts, where coals are cheap, they have been found very useful for raising considerable quantities of water. Several of them, after Savery's time, were erected by Mr. Joshua Rigley at Manchester, and throughout Lancashire, to impel the machinery of some of the earliest cotton-mills and manufactories of the district. One was, not very long ago, erected at the manufactory of Mr. P. Keir, at Camden-town. Fig. 12 is a representation of a central section of this engine. The boiler B feeds itself with water from a cistern by a pipe having a valve connected by a wire with a float on the water in the boiler, so as to open when the water gets low; for the float then sinks, and draws the valve up to allow the water from the cistern to supply the deficiency, but as the water in the boiler rises, the float closes the valve. Hence the water in the boiler remains nearly at the same height.

The steam is conveyed by a pipe C to a box D, through the bottom of which, by means of a conical valve, it is admitted to the cylindrical receiver A. The axis K serves as a key to open and shut this valve; H is a cistern from which the engine draws its water through a vertical pipe, having a valve at G to retain the water. F is another cistern into which the water is delivered from the receiver A through a valve; and thence it flows, through a sluice, upon the overshot water-

Fig. 12.



SAVERY'S ENGINE AND WHEEL.

wheel WW, of which the axis S communicates motion to the lathes and other machines used in the manufactory. The water falls from the wheel again into the lower cistern H. As the same water circulates continually in both cisterns, it soon becomes warm. To cool *this, cold water is* raised by a small forcing-pump from a well;

and a pipe passes from this pump to the conical part of the receiver A for injecting the cold water at the proper time. Upon the axis s of the water-wheel, another wheel, T, is fixed, shown separately, as at *a*, *b*, *c*, *d*, which are four clicks, all or any number of which may be fixed on the wheel at a time. Each wheel has its corresponding block, *e*, *f*, *g*, *h*, on the opposite surface of the wheel. The use of these is to work the engine. Thus, suppose the wheels are turning round, one of the clicks, *a*, meets a lever, which it lifts, and this opens the steam-valve D by a rod reaching the handle of the axis K. The steam then passes into the receiver A, and the steam-valve shuts again as soon as the click *a* has passed by. In the mean-time, the corresponding block *e*, on the other side of the wheel T, has been raising the loaded lever which forms the handle of the forcing-pump; and, at the instant the valve D is shut, the block *e* lets go the loaded lever to descend suddenly by its own weight. This depresses the forcer of the pump, and thereby throws a jet of cold water up into the receiver A, to condense the steam and create a vacuum. The pressure of the atmosphere upon the water in the cistern H then causes it to rise in the upright pipe, through the valve G, to the exhausted receiver. When the engine is first set to work, the water-wheel being motionless, the steam-valve and injection-pump are moved by hand; and, if the engine has been long out of work, two or three strokes may be necessary to raise water enough to fill the receiver A. As soon as this is done, and the valve opened to admit the steam into the receiver, the whole water above the spout and valve F flows out of the receiver A into the upper cistern. This machine, when in good order, delivered seven cubic feet of water in a minute, at the height of twenty feet above the reservoir, making ten strokes in a minute, and consuming six bushels of coal in twelve hours' work. The diameter of the overshot water-wheel W W was eighteen feet, and that of the wheel T, on the same axis, four feet.

In the practical application of Savery's engine, ingenious as it was, the only situations where it could be employed with perfect safety, and with useful effect, were those where the old lift did not exceed from thirty to thirty-five feet. In these the greater part of the work might be performed by the suction-pipe, and a very manageable pressure was sufficient for the rest. In greater lifts than this, its operation was both wasteful and dangerous. By some experiments, made by Dr. Robison, it appeared that no less than eleven-twelfths of the whole steam were uselessly condensed in the receiver, and not more than one-twelfth was employed in allowing the water to descend by its own weight. Many attempts were made to diminish this waste, not only in the early history of the engine, but even at a later period, as the records of the patent-office testify; but all of these attempts have failed, and this engine, the first that was invented of any practical utility, was at last entirely superseded.

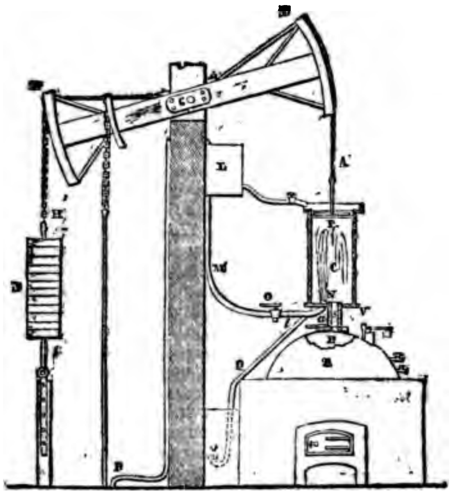
Thomas Newcomen, of Dartmouth, in Devonshire, having had occasion to witness experiments made with Savery's steam-engine in *the tin-mines* in Cornwall, and to observe the dangers and difficulties *attending their application* to the purposes of draining these mines, *was led to the consideration* of the best means of improving that

engine, or of substituting for it a new invention. In the latter scheme he succeeded to admiration; and many attempts were made to deprive him of this honour; but posterity has justly awarded to *Newcomen* the merit of having invented the *atmospheric steam-engine.* Although an ironmonger by trade, and associated with *John Cawley*, a glazier of the same town, in the construction of his engine, he appears to have been the sole inventor, as attested by documents in the possession of the Royal Society, containing his correspondence with the celebrated Dr. Hooke, F.R.S., on the subject. The latter seems to have dissuaded Mr. Newcomen from attempting to erect a machine to draw water from mines on an impracticable principle proposed by Dr. Papin—a principle of which the fallacy has been exposed by him in several discourses before the society; but he added these remarkable words:—"Could he (Papin) make a *speedy* vacuum under your second piston, your work is done." From this remark it would appear either that the method of forming a vacuum under a piston by the condensation of steam, previously discovered by Dr. Papin, was unknown to both, or that the condensation effected by this method was *not sufficiently rapid* for the purpose required. The next step, therefore, to effect this *rapid* condensation in the cylinder, was to apply Savery's principle of condensation, by the application of cold water to it, in the same manner as was done to the receiver. This Newcomen at once did, and thereby overcame the chief difficulty in the construction of his new engine. This method of obtaining a vacuum by the condensation of steam, whatever might be the shape of the vessel, was, however, the property of Captain Savery, and it had been secured to him by a patent; consequently, Newcomen could not use it in his engine until a negotiation had been entered into between the parties. The result of this negotiation was that a new patent was obtained in 1705, in which the names of *Savery*, *Newcomen*, and *Cawley* appeared as partners in the invention. It was, nevertheless, well enough known that the only assistance which Savery rendered to the invention was granting permission to use his patent method of obtaining a vacuum, while that rendered by Cawley appears to have been chiefly, if not wholly, mechanical. Fig. 13 is a representation of the vertical section of Newcomen's steam-engine, commonly called the *atmospheric engine.*

The large boiler B, for generating the steam, is built in a furnace of brickwork. At a small height above it, is a metal cylinder C, bored truly—that is, of equal diameter throughout. The boiler communicates with this cylinder by means of the steam-pipe S. The lower part of this pipe is shut by a plate, which is ground very flat, so as to apply very accurately to the whole circumference of the orifice. This plate is called the regulator or *steam-cock*, and it turns horizontally round an axis at *a*, fitted at the top of the boiler, and furnished with a handle. A piston P is suspended in this cylinder C, and made air-tight by a packing of leather or tow, a quantity of water being kept on the top for greater security. The piston-rod AP is suspended by a chain, which is fixed to the upper extremity D of the arched head of the great lever or *working-beam* which turns on the gudgeon G. There is a similar arched head at E, on the other end of the beam. To its

upper extremity is fixed a chain carrying the *pump-rod* H, which raises the water from the mine. To this rod is attached a *counter-weight* I, which exceeds considerably the weight of the piston P at the other extremity. At a small height above the top of the cylinder is the cistern L, called the *injection-cistern*. From this descends the injection-pipe M, which enters the cylinder through its bottom, and terminates in a small hole N, or sometimes in a nozzle pierced with smaller holes, diverging from a centre in all directions. This pipe has a cock at O, fitted with a handle, and called the *injection-cock*. The injection cistern is filled by a pipe R, which is supplied by a small forcing-pump which raises the water from the well filled by the pump-rod. The rod of the forcing-pump is attached to the same arm of the working-beam as the great pump-rod H. From the injection-cistern a small pipe, furnished with a cock, passes to the top of the piston, to supply it with water to make it air-tight. At the opposite side of the cylinder, near the bottom at V, is a lateral pipe, turning upwards at the extremity, and there fitted with a clack-valve called

Fig. 13.



NEWCOMEN'S ATMOSPHERIC ENGINE.

the *snifting valve*, which has a little dish round it to hold the water used for keeping it air-tight. From the bottom of the cylinder there also proceeds a pipe Q, of which the lower end is turned upwards, and is furnished with a valve *v*. This part is immersed in a cistern of water called the *hot-well*, the pipe itself being called the *eduction-pipe*. The boiler is furnished with a *safety-valve* called the *puppet-*

clack, and gauge-cocks, in the same manner as that of Savery's engine. The safety-valve is generally loaded with a weight of one or two pounds to the square inch, so that it allows the steam to escape when its elasticity is, on an average, only one-tenth greater than that of common air. Thus all risk of bursting the boiler is avoided, and the pressure outwards, as well as the heat, are very moderate.

The operation of this engine is as follows:—The water in the boiler having produced a sufficient quantity of steam, as indicated by the emission of steam from the puppet-clack, suppose the machine to be at rest, having both the steam-cock and injection-cock shut, with the pump-rods preponderating, and the great piston P drawn up to the top of the cylinder C. Then, if the steam-cock at *a* be opened by turning the handle, the steam will immediately rush into the cylinder, and drive out the air it contains by the snifting-valve; but it will at first be condensed by the cold sides of the cylinder and piston, and the water trickling down, will escape by the eduction-pipe. This process will continue only till the cylinder and piston within are made as hot as the steam itself, when it will also begin to escape through the snifting-valve. As soon as the puppet-clack begins again to emit a little steam, the steam-cock *a* is shut, and the injection-cock O is opened. The pressure of the water in the injection-pipe M immediately forces some water through the hole N, which, mixing with the steam in the cylinder C, begins to condense it, and the snifting-valve and eduction-valve are shut by the pressure of the atmosphere. The steam in the cylinder being nearly all condensed, the whole pressure of the atmosphere will act upon the upper surface of the piston, without meeting any resistance from the condensed steam; and this pressure being greater than the load at the other end of the beam, it will overcome its weight, and cause the piston P to descend. The pump-piston will then begin to ascend, bringing along with it a column of water from the mine, and this motion will continue till the piston P reaches the bottom of the cylinder. At the proper instant, the injection-cock is shut, and the steam-cock is opened; the steam, which has been accumulating during the time of the descent of the piston, now rushes into the cylinder with greater elasticity than that of the air; it therefore at once blows open the snifting-valve, and allows the water in the cylinder, arising from injection and condensed steam, to descend by its own weight through the eduction-pipe Q and the valve *v* into the hot-well. But the piston also begins to ascend at the moment the steam-cock is opened; for the atmospheric pressure on the upper surface of the piston is now counterbalanced by the pressure of the steam on its under-surface, and the counterweight I is heavier than the piston P. Besides raising the piston of the cylinder, the counterweight also causes the pump-pistons to return through the water to their places at the bottom of their working-barrels, in order that they make another working-stroke. The effect of the counterweight is very different in the two motions of ascent and descent. The engine, when making a working-stroke, is lifting not only the column of water in the pump, but also the absolute weight of the pump-pistons and pump-rods; but when the latter are descending, there is a diminution of the pressure of the

counterweight by the whole weight lost by their immersion in water. These two motions complete the period of one operation, and the whole may be repeated by shutting the steam-cock, and opening the injection-cock, whenever the piston has reached the proper height in the cylinder.

From the preceding description of the operation of Newcomen's engine, the great difference between it and Savery's engine, in point of principle, will be rendered manifest. In Savery's engine, water was raised partly by the force of steam, and *partly* by the pressure of the atmosphere; in Newcomen's engine, water was raised *entirely* by the pressure of the atmosphere, steam being only employed alternately to create a vacuum, and to restore the equilibrium destroyed by that vacuum. The atmospheric pressure is, therefore, deemed the *Prime Mover* in Newcomen's engine, and not the elasticity of steam. The superiority of this new machine is immense. There is no need of employing steam of great and dangerous elasticity; moderate heat, and consequently much smaller quantities of fuel are required. The limits to the power of this machine are not the strength which can be given to boilers and cylinders to resist internal pressure, but the dimensions which it may be found practicable and expedient to make these and other parts of the machine. Moreover, the form of the machine is such that it can be rendered applicable to other industrial purposes than that of raising water, a property in which Savery's engine was peculiarly defective. To employ either Newcomen's or Savery's engine, however, in raising water to turn a common mill-wheel, is to convert them into *rotary engines of medial effect*, and to create a loss of power to a very considerable extent. In general, such engines may be defined as those which do not immediately give revolution to an axis, by the action of the steam upon the wheel, but have a medium of communication between the power and the effect. A variety of this class of engines has been invented, of which the *Fire-wheel* of *Amontons* is a generic example. The steam pushes water through certain channels that form the arms of the wheel, from a set of chambers on one side of the wheel, to a corresponding set of chambers on the opposite side, and thus the side filled with water preponderates over the other, and the wheel revolves. The water being constantly driven off by the steam from a given side of the wheel to that opposite, uniform revolution is the result of the weight of the water. In this case, although steam is the agent, water is the means of communicating the rotary motion. Instead of water, weights, in the form of pistons, have been transferred by the force of steam to a considerable distance from the centre on one side of a wheel, and drawn nearer to it on the other side, so as, by bringing about a continual preponderance of one side, to effect a revolution. In this class of engines the loss of effect is obvious; for it is necessary that the steam, in order to produce the circular motion, should give out its force in setting the medium in motion, and in overcoming the very great resistance of the liquid in all the pipes, passages, and valves, through which it is admitted to alternate sides of the wheel *in every revolution*. The loss of effect encountered in all modes *hitherto adopted for* applying a fluid to the rotation of a wheel, has

in the best examples ever tried, exceeded, at least, a sixth part of the power.

Newcomen's engine was at first in a considerably less perfect state than that which we have described; and many defects and inconveniences had to be gradually removed. The condensation of steam in the cylinder was at that time performed by the application of cold water on the outside of it, instead of in the inside, a process which both wasted water and unnecessarily cooled the cylinder; also the greatest nicety and attention on the part of the engineer was required, in order to turn the steam and injection cocks at the proper instant. For, if the steam were permitted to enter the cylinder for too long a time, the piston would be carried so high as to be blown out of its place; while on the other hand, if the steam-cock was not opened soon enough when the piston was descending, it would strike against the bottom of the cylinder with such force as to break it to pieces. The invention of the snifting-valve was also a work of pure necessity, and one which preceded the adoption of the eduction-pipe, whose work it was at first obliged to perform. Although the patent for Newcomen's engine was granted in 1705, seven years elapsed before the invention was reduced to a working state. The patentees, towards the end of the year 1711, made proposals to draw the water at Griff, in Warwickshire, but they were not accepted. In March 1712, however, they made an agreement to draw water for Mr. Back of Wolverhampton; where, after many laborious attempts, they at last got their engine to work. Dr. Desaguliers, who mentions these particulars, states that "they were at a loss about the pumps, but being so near Birmingham, and having the assistance of so many admirable and ingenious workmen, they soon came to the method of making the *pump-valves, clacks, and buckets*; whereas they had but an imperfect notion of them before. One thing is very remarkable. At first working, they were surprised to see the engine go several strokes and very quick together; when after a search [for the cause], they found a hole in the piston, *which let the cold water in to condense the steam in the inside of the cylinder*, whereas, before, they had always done it on the outside. They used, before, to work with a buoy in the cylinder inclosed in a pipe; which buoy rose when the steam was strong, and opened the injection-pipe and made a stroke, whereby they were capable of only giving six, eight, or ten strokes in a minute, till a boy named Humphrey Potter, who tended the engine, added what he called *scoggan* [skulking apparatus], *by which the beam of the engine always opened and shut its own valves*, and then it would go (entirely without attendance) fifteen or sixteen strokes in a minute. But this being perplexed with catches and springs, Mr. Henry Beighton, in an engine he had built at Newcastle-on-Tyne, in 1718, took them all away, *the beam itself supplying all much better*." It is true that Mr. Beighton, who was a very ingenious and well-informed mechanist, simplified the whole of the subordinate movements of this engine, and brought it into the form in which it continued, without any material change, for more than half a century. But it must be remembered that Newcomen gave to the steam-engine the working beam, and the

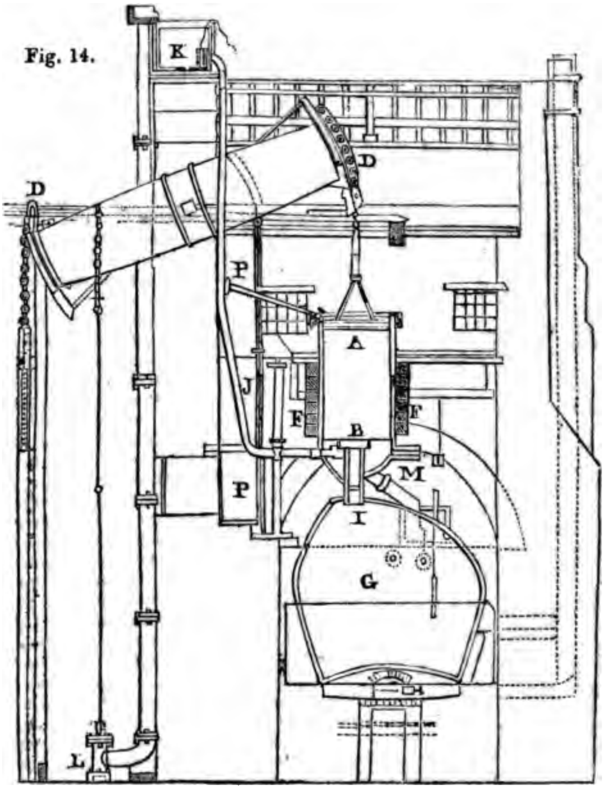
cylinder and piston; that he first formed *a vacuum in the cylinder below the piston*; and that he gave to the *valves, clacks, and buckets the improved construction*, which rendered them suitable to the precise action of steam. He first constructed *a piston with an elastic packing of hemp*, by which it is kept steam and air-tight as it moves up and down the cylinder; and, above all, that he availed himself of the result of an accident, which may be termed lucky, to add the important process of *condensing steam by injecting cold water amongst it*. All these inventions of Newcomen give to the modern steam-engine some of its most important features.

The apparatus by which Mr. Beighton enabled the atmospheric engine itself to open and shut the valves for admitting and shutting off the steam, &c., and to dispense with the labour of attendance, was principally effected by means of a rod suspended from the beam, and called by him the *plug-tree*. This acted upon certain levers and catches for working the valves, and gave to the engine the first claim to be considered automatic. In fact, Newcomen, Potter, and Beighton, had rendered the atmospheric steam-engine an independent self-acting mechanical power, of such great perfection in its principle of action, as well as in its minor details, that it was very generally introduced as a substitute for animal power in the mining districts. But the consequent rapid progress of mining industry soon put the capabilities of this engine to a severe test. The dimensions of the cylinders in the earlier engines varied from twelve to sixteen inches in diameter; in the later engines they gradually increased to sixty inches in diameter. The other parts of the engines were necessarily increased in proportion; and at last their construction became so gigantic, that it demanded all the science and practical skill of the engineers who flourished in the latter half of the eighteenth century. The famous Smeaton lent his engineering experience to the perfection of some of the large erections which the demands for steam-power in his time began to require. He produced machines which surpassed in dimensions and efficiency all that had been previously constructed. At Long Benton colliery, near Newcastle, he erected his standard engine in 1772. The diameter of its cylinder was 52 inches, depth of stroke 7 feet, and number of strokes per minute 12. Its load of water was 7 tons 2 cwt. The load per square inch was 7½ lbs. The consumption of coals was 17 lbs. 10 oz. per horse power per hour; and the work of one bushel, or 84 lbs., of coals was 9,450,000 lbs. raised one foot high. The total power of the engine was about 41-horse power, and for every horse-power, the boiler had 52 cubic feet of total space, 27¾ cubic feet of steam-room, and 6¼ square feet of horizontal surface of water. The furnace had for every horse-power 3¼ square feet of fire-surface, 7, 5-6th square feet of flue-surface, and ⅙th of a square foot of fire-grate. The total steam produced per minute was about 63 cubic feet per horse-power, of which about 30½ were used in moving the piston, 9 wasted to fill the extra space in the cylinder, and 23¼ condensed on the surface of the cylinder.

The great Chasewater engine was the most magnificent effort of Smeaton in this department of engineering. It was erected in 1775;

its details are given in his reports, and they are remarkable for judicious arrangement and ingenious contrivance. A representative sketch of this atmospheric engine is given in Fig. 14.

Fig. 14.



SMEATON'S CHASEWATER ENGINE.

The cylinder AB is 72 inches in diameter, and the stroke 10 feet 6 inches. The great lever or working-beam of the engine DD consists of twenty large balks of timber, the four nearest the centre being each a foot square. The whole are firmly joggled together with heart of oak, and bolted with iron, forming an elegant but ponderous

mass. The beams FP, on which the cylinder rests, are preserved in their place by being fixed into the sidewalls of the engine-house; they are joggled and framed together in a manner very similar to the great beam. G is the boiler; H the furnace; IB the steam-pipe; J the injection-pipe; K the injection cistern, which is fed by a pump L, worked by the great lever; and M the waste-pipe for the condensed steam. Suspended from D, on the left arm of the great beam, is the spear or rod of the great draining-pump, which is worked by the engine. PP is the plug-tree, suspended also from the great beam, and carrying plugs, which in their upward and downward motion act on the levers which open and shut the regulator and injection-cocks. The working-gear of this engine is very simple, ingenious, and well adapted for the purpose; but the engraving of the engine is on too small a scale to admit of its being seen in connection with the parts to which it is attached. This, however, is of less importance, as in modern times it has been altogether superseded. This great engine was one of 150-horse power, and delivered 880 hogsheads, or 48,330 imperial gallons, of water per hour, by the consumption of 16¼ bushels of coal. Hence, the duty performed by this engine was 18,500,000 lbs. raised one foot high.

When we consider the enormous force brought into action in the cylinder of such an engine as the preceding, during the time that it is at work, the impropriety of fixing the cylinder directly over a boiler supported above a strong fire, must be evident. However strongly built the brickwork of the fireplace might have been, still it was subject to rapid decay from the action of the fire, and to a consequent derangement of the whole apparatus of the machine in its immediate neighbourhood. Notwithstanding the great improvements effected by Mr. Beighton, who introduced the system of supporting the cylinders between strong timbers let into the walls of the building where the engine stood, so as to prevent them from resting altogether upon the brickwork of the boiler, yet there was so much powerful vibration in these machines, from their massiveness, that the furnaces were soon shaken and destroyed. The great piston, in its upstroke, would actually lift up the entire boiler and cylinder, which were strongly bolted together, as much as the springing of the timbers would allow, and it would depress and replace them in the downstroke; nor could the most careful construction prevent this serious inconvenience. As an example, it was witnessed in the action of an atmospheric engine, one of the most perfect that was erected by Mr. Smeaton, at the York Buildings Water Works in Villiers-street, Strand, and which was pulled down in 1813, to make room for one of the more perfect machines of Messrs. Watt and Boulton. The defect thus experienced was in some cases removed, by resorting to the construction at first adopted by Captain Savery, of placing the cylinder beside the boiler, instead of over it, and bolting it down to a solid and massive block of brickwork and masonry, which had no connection with the furnace. This plan insured much greater stability, and dispensed with the great height, and consequent expense of the engine-house. The atmospheric steam-engine having been for many years considered as perfect an engine as the

nature of things would admit, the attention of those who took an interest in its applications, was chiefly directed to the prevention of its enormous consumption of fuel. Many experiments were made on different forms of boilers, with a view to solve the question—what shape should be given to a steam-boiler in order that it may produce the greatest quantity of steam with the smallest quantity of fuel? It was very soon discovered that the best form was that which exposed the greatest quantity of surface to the action of the fire, and did not permit its heat to pass up the chimney, until nearly the whole of its power had been exhausted. With this principle in view, Mr. Smeaton directed some of his boilers to be constructed in such a manner that the flame and smoke should pass through a complete labyrinth of channels; but the great number of turnings and corners that were thus exposed to the action of the fire rendered them very liable to be destroyed, and made the construction of a boiler greatly more expensive, without producing a proportionably beneficial result. The truth was, that the radical error existed in the construction of the engine itself, and not in the shape of the boiler. Accordingly, until this error was discovered and corrected, the saving of fuel by other means was but a secondary consideration.

For a period of more than half a century, the use of the atmospheric-engine was entirely confined to the raising of water. The progress of the arts and manufactures of this country demanded some essential improvement in its construction and application; and sooner or later this would have been brought about. A civic crown, more glorious than those which graced the victors of the Olympic games, awaited the mighty genius who should overcome all the practical difficulties which stood in the way of such an important invention. The attention of many, though now to us unknown, was no doubt directed to this anticipated effort of human ingenuity. Among others, Mr. Keane Fitzgerald published in 1758, (Phil. Trans.) a method of converting the reciprocating motion of the engine-beam into a continued rotary motion, by employing "a combination of large toothed-wheels, and of smaller ratchet-wheels, worked by teeth upon the arch or sector of the beam. One of these ratchet-wheels being put in motion by the ascent of the beam, and standing still during its descent, another ratchet-wheel is moved by an intervening wheel in the same direction as the first; and thus, the two communicate a continued rotary motion to the axis on which they are placed, which is thence transmitted by a large toothed-wheel to a smaller wheel or pinion, on the shaft of which is a fly, to accumulate momentum, and a crank proposed to be applied to work ventilators, and to many other useful purposes. The fly, by accumulating in itself the power of the machine during the time it was acted upon, would continue in motion, and urge forward the machinery whilst the steam-engine was going through its returning stroke." Theoretically speaking, this scheme of producing rotary motion is very possible and easy, provided that the resistance exerted by the working part of the machine during the whole period of the working and returning strokes of the steam-engine, including the friction of both, does not exceed the whole pressure exerted by the engine during its working-stroke; and that the

momentum of the fly, arising from its weight and velocity be so great, that the resistance of the work during one returning stroke of the engine does not make a very sensible diminution of the velocity of the fly. The fly on this principle may be made of any magnitude; and being exactly balanced round its axis, it will soon acquire any velocity consistent with the motion of the engine. During the working-stroke of the engine, it is uniformly accelerated, and by its acquired momentum, it produces in the beam the movement of the returning stroke; but in doing this, its momentum is communicated to the inert matter of the engine, and consequently its velocity is diminished. The next working-stroke, by pressing on it anew, increases its remaining velocity by a quantity nearly equal to the whole acquired during the first stroke; nearly only, because the time of the second working-stroke must be shorter than the first, on account of the velocity already acquired. In this way, the velocity of the fly will be accelerated in each succeeding stroke, because the pressure of the engine during the working-stroke does more than restore to the fly the momentum which it lost in producing the returning movement of the engine. If, now, the working part of the machine be added, the acceleration of the fly during each working stroke will be less than before, because the impelling pressure is partly employed in driving this working part, and the fly will lose more of its momentum during the returning stroke on this account. From these considerations, it is evident that a period will arrive when the successive increase in the velocity of the fly will cease; for the continual acceleration diminishes the time of the successive working-strokes, and consequently the time of the action of the accelerating power. This will happen whenever the addition made to the momentum of the fly during a working-stroke of the engine is just equal to what it loses by driving the working part of the machine, and by effecting at the same time the returning stroke of the engine. This invention must be acknowledged as a very important and ingenious addition to the steam-engine, but one requiring considerable skill and address to render it effective and useful. The movement of the working-machine or mill of any kind, to which the engine may be applied, must be in some degree oscillatory or unequal; but it may be rendered quite insensible, by making the fly exceedingly large, and throwing the greatest part of its weight into the rim of the wheel. By such means, its momentum may be made so great, that the whole of the force required for driving the mill and effecting the returning motion of the engine, may bear a very small proportion to it. The diminution of its velocity will then be very small. By this contrivance, Mr. Fitzgerald hoped to render the steam-engine of very extensive use; but it appears never to have been carried into actual practice. It has, in fact, been superseded by later inventions constructed on a similar principle, but of a simpler kind.

CHAPTER IV.

PROGRESS OF THE STEAM-ENGINE, FROM THE ERA OF WATT, TO THE END OF THE EIGHTEENTH CENTURY.

During the latter half of the eighteenth century, a galaxy of illustrious men appeared in Britain, who shed a lustre on the arts and sciences of this country which has not yet been surpassed. The University of Glasgow possessed the lion's share of the *eclât* which arose from the important discoveries of that period. *Dr. Robert Simson*, its Professor of Mathematics, had restored the ancient Geometry to its pristine accuracy and elegance, and descended into the vale of years one of its brightest ornaments. *Dr. Matthew Stewart*, his pupil, had applied that geometry to the solution of problems which belonged to the *new Calculus*, and had been transferred to the University of Edinburgh, as the successor of the celebrated *Maclaurin*. *Dr. James Moore*, its Professor of Greek, had rescued the richest language of antiquity from the jargon of the schools, and still shone as an ornament of the university. *Dr. Adam Smith*, its Professor of Moral Philosophy, had founded his new theory of moral sentiments, and established the true principles of the "wealth of nations." *Dr. Black*, its lecturer on Chemistry—afterwards transferred to the University of Edinburgh, as professor of the same science—had discovered the important principle of *latent heat*. *Dr. John Robison*, his pupil, and afterwards Professor of Natural Philosophy in the Metropolitan University, was the friend and companion of Watt; and *James Watt* himself was then *mathematical instrument maker* to the *University of Glasgow*. He was born at Greenock, the port of Glasgow, in 1735, and came to the latter city, at the age of twenty-one, as a common working mechanic and optician. His acquaintance with Dr. Robison began in 1756, when the latter was seventeen years of age; and between that period and 1758, his attention was turned to the subject of the steam-engine by his friend, who suggested that it might be applied to giving motion to wheel-carriages, and that, for that purpose, it would be most convenient to place the cylinder with its open end downwards, to avoid the necessity of using a working beam. In consequence of this suggestion, he began a model with two cylinders of tin-plate, to act alternately, by means of other mechanism, on two pinions attached to the axles of the wheels of the carriage. But the model did not answer his expectation. Robison having left the University, Watt continued, from time to time, to make detached experi-

ments on steam. In 1761, he tried some experiments of this nature in a Papin's digester, and formed a kind of steam-engine by fixing upon it a syringe one-third of an inch in diameter, furnished with a solid piston, a cock to admit or exclude the steam from the digester at pleasure, and another to open a communication with the interior of the syringe and the open air, so that the steam in it might be allowed to escape when required. When the communication between the digester and the syringe was opened, the steam entered the syringe, and, by its action upon the piston, raised a considerable weight (15 lbs.), with which it was loaded. When this was raised to a certain height, the communication with the digester was shut, and that with the atmosphere was opened; the steam then escaped, and the weight descended. He repeated these operations and inferred that they might be made, by the machine itself, to work with perfect regularity. Mr. Watt soon relinquished the idea of constructing an engine on this principle, from the consideration that it would be liable to some of the objections that attended the use of Savery's engine—namely, the danger of bursting the boiler, the difficulty of making the joints tight, and the loss of a great part of the force of the steam, because no vacuum was formed to effect the descent of the piston.

His attention was withdrawn from the subject till 1763, when it was revived by the circumstance of a model of Newcomen's engine being sent to him to be repaired from the cabinet of the natural philosophy class of the university. Mr. Watt confesses that, at this period, he had read and studied the works of Desaguliers and Belidor (already referred to in the previous chapter). From these, no doubt, he would learn what had been done by Dr. Papin, Captain Savery, and Mr. Newcomen. He set about repairing the model as a mere mechanic; and when it was repaired and put in operation, he was surprised to find that the boiler belonging to it could not furnish a sufficient supply of steam, although apparently large enough for this purpose, for the cylinder of the model was only two inches in diameter, and six inches stroke, while the boiler was about nine inches in diameter. By blowing the fire, the machine was made to effect a few strokes; but it required an enormous quantity of injection water, although it was very lightly loaded with the column of water in the pump. It soon occurred to him that this was caused by the fact that the cylinders of small engines expose a greater surface to the condensation of their steam than the cylinders of large engines do, in proportion to their capacity. He seems to have been well aware of the mathematical principles, that solids are to one another as the *cubes* of their dimensions, but that their surfaces are to one another only as the *squares* of their dimensions. He found, by shortening the column of water in the pump, the boiler could be made to supply the cylinder with steam, and that the machine would work regularly with a moderate quantity of injection-water. He also found that the cylinder of the model, being made of brass, conducted heat much better than the cast-iron cylinders of large engines, which were generally covered on the inside with a stony crust, and that considerable advantage would be gained by making the cylinders of

some substance, that would receive and give out heat slowly. Wood seemed most likely to answer this purpose, provided it were found sufficiently durable. Accordingly, he made a small engine, of six inches diameter and twelve inches stroke, of wood, soaked in linseed-oil, and baked to dryness. With this engine he made many experiments; but he soon found that the wooden cylinder would not prove durable enough, and that the steam condensed in filling it, still exceeded the proportion of that required for large cylinders, according to the statements concerning them, given by Dr. Desaguliers. He found, also, that all attempts to produce a better state of exhaustion, by throwing in more injection-water, occasioned a disproportionate waste of the steam. Meditating on the cause of this, he attributed it to the fact, that water boiled *in vacuo* at low heats (100 deg. Fahrenheit), a discovery made by *Dr. Cullen*, the predecessor of Dr. Black, in the University of Glasgow; and he naturally inferred that, at greater heats, the water in the cylinder would produce a vapour, which would partially resist the pressure of the atmosphere. We now know that the vapour of water, at 180 degrees, is equal to half the pressure of the atmosphere.

Mr. Watt proceeded to make experiments on the degrees of heat at which water boils, under several pressures, *greater* than that of the atmosphere, and found that, when the degrees increased in an arithmetical, the elasticities increased in some geometrical ratio. He then drew a curve, which represented the relation of these ratios, by making the numbers representing the degrees and the elasticities, the ordinates and the abscissæ, of that curve. He also found that an approach to a vacuum could only be obtained by throwing large quantities of injection-water into the cylinder, which cooled it so much as to require quantities of steam to heat it again, considerably out of proportion to the force gained by the more perfect vacuum thus obtained, and that the older engineers had acted wisely in confining the load on the engine to about six or seven pounds on each square inch of the piston. It may be proper here to state that experiments have been made on a very large scale to determine the law of the increase of the elasticity of steam according to the temperature, but that no general rule or formula has yet been elicited, which will correspond exactly with the result of the most careful experiments. When steam, by continual accessions of heat, acquires an elastic force capable of supporting a column of sixty inches of mercury, or *twice* the height of the barometric column, it is then said to possess a force of *two* atmospheres. When it can support a column of ninety inches of mercury, or twice the height of the barometric column, it is said to possess a force of *three* atmospheres, and so on, in proportion to the height of the column of mercury which it can support. By the experiments of *Taylor*, the force of steam was determined as far as 180 inches of mercury, or a pressure equivalent to *six* atmospheres. Beyond this point, the determination of the force of steam is due to the labours of *MM. Dulong* and *Arago*, the chief members of a commitee appointed to investigate the subject by the Academy of Sciences in 1829. The temperatures and corresponding pressures were determined experimentally as far as twenty-four atmospheres, and thence

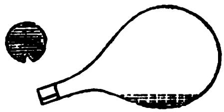
they were extended up to fifty atmospheres, by calculation, according to a formula empirically ascertained by these philosophers. This formula, when expressed in the words of a rule, is the following, which is given for the benefit of the practical reader. The table, calculated up to fifty atmospheres, and including the results of the experiments above-mentioned, will be placed at the end of the book. *To find the elasticity of steam at very high temperatures*:—Rule. *Subtract* 212 *degrees from the given temperature, multiply the remainder by the decimal* .003974, *and add* 1 *to the product; then raise the sum to the fifth power, and it will give the elastic force required in atmospheres.* If the pressure be required in inches of mercury, it will be sufficient to multiply the last result by 30 to obtain the answer.

As Dr. Desaguliers had related some experiments made by Mr. Beighton on the consumption of steam by an atmospheric engine, which led to erroneous conclusions on the expansion of steam, and particularly that it was 14,000 times rarer than water, Mr. Watt made the following experiments, with a view to determine the amount of its expansion as compared with the water from which it was generated. He took a Florence flask, capable of containing about a pound of water, put about an ounce of distilled water into it, fitted a glass tube into its mouth, and made the joining tight with pack-thread and putty. He placed the flask upright, with the tube reaching within nearly to the surface of the water, and placed the whole in a tin reflecting-oven, before a fire, until the water had slowly and wholly evaporised at a heat rather above boiling water. As the air in the flask was heavier than the steam, the latter ascended to the top, and expelled the air through the tube. When the water was all vaporised, which took place in an hour, the oven and flask were withdrawn from the fire, and a blast of cold air was directed against one side of the flask, to collect the condensed steam into one place. When the whole was cold, the tube and its fittings were removed, and the flask and its contents were weighed with care; the flask was then made hot, and dried by blowing into it with a pair of bellows; it was again weighed, and found to have lost rather more than four grains, or about four and one-third grains, which was, of course, the weight of the condensed steam. When the flask was filled with water, it was found to weigh about seventeen and one-eighth ounces avoirdupois; this gave, as Mr. Watt says, "about 1800 times for the expansion of water converted into steam of the heat of boiling water." The exact calculation of this experiment is the following:—the densities of different bodies being proportional to the weights of equal quantities of these bodies, we have the density of steam : the density of water : : 4⅓ grains : 17⅛ ounces, or, as 104 : 359625; this being reduced, gives the ratio as 1 : 1728 very nearly; whence, as has been often said, *a cubic inch of water can be converted into a cubic foot of steam, and its elasticity will still be such as to resist the pressure of the atmosphere.* Mr. Watt repeated the preceding experiment with nearly the same result.

In order to ascertain whether the flask had been wholly filled with steam in these experiments, Mr. Watt, at the suggestion of Dr. Black, with whom also he had formed an intimacy at the university, vapo-

rised a similar quantity of water, a third time; and while the flask was in its cool state, it was inverted, and placed, without removing the tube, with its mouth immersed in a vessel of cold water; the water immediately began to rise in the flask, and continued to do so until the temperature of the whole was the same as that of the atmosphere, when the flask was found to be filled with water to within a very small quantity.

Fig. 15.



WATT'S APPARATUS.

In repeating the same experiment at a later date, Mr. Watt simplified the apparatus by omitting the tube, and laying the flask on its side in the oven, as in Fig. 15, partly closing its mouth by a cork having a notch on one side; he then conducted the rest of the experiment as before. As he had not a very sensible scale-beam at command whilst conducting these experiments, he did not consider them extremely accurate, and was inclined to think the expansion of steam somewhat greater than that given by the preceding computation. In this, however, he was slightly mistaken, and the rule above derived from his own experiments may be considered as sufficiently accurate for all practical purposes. Experiments were made in France, by Gay-Lussac, and others, to determine the expansion of steam, and it has been found that the density of water is to that of steam, as 1683 to 1, by one experimenter; and as 1696 to 1, by another; being somewhat less than the ratio above determined by Watt. Taking the ratio of 1700 to 1, as nearly a mean between the smaller of these ratios and that of Watt, this may be considered as the result which is nearest to the truth.

Mr. Watt, in continuing his experiments on the steam-engine, constructed a boiler which showed by inspection the quantity of water vaporised in any given time, and he thereby ascertained the quantity of steam used at every stroke of the cylinder; this he found to be several times the full of the cylinder for each stroke. Surprised at the quantity of water required for injection, and the great heat which it acquired from the small quantity in the form of steam which was used in filling the cylinder, he thought he had committed an oversight, and endeavoured to rectify it by the following experiment. He took a tube bent at right angles, and inserted one end of it horizontally in the spout of a tea-kettle; he then immersed the other end vertically in cold spring water contained in a cylindric glass vessel; steam was now permitted to pass through the tube into the vessel, until its condensation ceased by the water in the cylindric vessel becoming nearly boiling hot. The water in this vessel was then found to have gained an addition of about one-sixth part from the condensed steam. He accordingly inferred that water converted into steam can heat about six times its own weight of water to 212 degs. Fahrenheit, or till it can condense no more steam. Struck with this remarkable fact, he related the circumstances to his friend Dr. Black, who then explained to him the doctrine of Latent Heat, which he had

discovered and taught for some time previous to the date of this experiment, the summer of 1764. Thus Mr. Watt, unknown to himself, had discovered one of the most convincing facts by which that beautiful theory is demonstrated.

The method by which Dr. Black ascertained the quantity of latent heat absorbed by water in its conversion into steam, may be here mentioned. If a given weight of water be exposed to a regular source of heat, and the time required to raise it from a given temperature, say 50 degs., to its boiling point, be observed, the rate at which it receives heat per minute, may be computed. If the time be noted which elapses from the commencement of the ebullition to the entire disappearance of the water; and, if it be assumed that in each minute the same quantity of heat was communicated to the boiling water as was imparted before ebullition commenced, the quantity of the heat carried off by the steam may easily be calculated. Some water placed in a tin vessel on a red hot iron, was observed to rise from 50 deg. to 212 deg. in four minutes, being at the rate of 40½ deg. per minute. The same water boiled off into steam in twenty minutes; now if it received during each of these twenty minutes 40½ deg. of steam, it must have carried off as much heat in the form of steam as would be sufficient to raise water through twenty times 40½ deg., that is, 810 deg. Again, if water submitted to pressure be raised to the temperature of 400 deg. and the mouth of the vessel which contains it be suddenly opened, about one-fifth of the whole quantity of water will escape in the form of steam, and the temperature of the remainder will fall suddenly to 212 deg. Thus, the whole mass of water has suddenly lost 188 deg. of temperature, which is all carried off by one-fifth of the mass in the form of steam. The heat, therefore, which has become latent in the steam will be determined by multiplying 188 deg. by 5, which gives 940 deg. The steam is thus composed of water and of 940 deg. of heat, the presence of which is not indicated by the thermometer. The experiment of Watt, above-mentioned, appears to us a more accurate experiment for the determination of the latent heat of steam. For assuming the temperature of the spring water in his cylindrical vessel to be 50 deg. which it generally is in the climate of Glasgow, it is evident that six times its own weight of water had been raised from 50 deg. to 212 deg., or through 162 deg. of temperature. Accordingly, six times this quantity, or 972 deg. is the heat absorbed by raising any given quantity of water from the temperature of 50 deg. to that of 212 deg. This result is higher than that obtained by Dr. Black, and corresponds more closely with various experiments made by Watt himself, and others.

In consequence of these new and striking experiments on steam, Mr. Watt began to consider how he could make the best use of his discoveries in their application to the steam-engine. He saw *first*, that the cylinder should always be kept, if possible, in as hot a state as the steam which entered it; and *secondly*, that when the steam was condensed, the water both of condensation and injection should be cooled down to 100 deg. or lower, if it could be done. He did not at once perceive how these objects could be effected; but in the begin-*ning of 1765, the thought* occurred to him, *that if a communication*

were opened between a cylinder containing steam, and another vessel which was exhausted of air and other fluids, the steam, being an elastic fluid, would immediately rush into the empty vessel, and continue to do so until it had established an equilibrium in both vessels; and farther, that if the empty vessel were kept at a very low temperature, by injection-water or otherwise, more steam would enter into it until the whole contents of the cylinder were condensed. ADMIRABLE DISCOVERY! Thus was accomplished, by a single thought, that which had been considered impossible by all previous engineers, namely, *the production of a vacuum without cooling the cylinder.* The next inquiry was, that supposing both the vessels to be exhausted, or nearly so, how were the injection-water, the air that might enter with it, and the condensed steam, to be extracted from them? Two methods suggested themselves to his mind; *first,* to adapt to the second vessel, which may now be called *the condenser,* a pipe reaching downwards more than 34 feet, by which the water might descend, seeing that a column of this length would overbalance the atmosphere, and then to extract the air by means of an air-pump; *secondly,* to employ a pump or pumps to extract both the air and the water, which might be applicable in all places, and positively essential in those engines where there was no well or pit. He preferred the latter method, of course, and it was the only one which he afterwards continued to employ.

Mr. Watt found that other improvements on the atmospheric engine would be necessary in order to render the preceding discoveries available. In Newcomen's engine the piston is kept air and steam-tight by the water applied on the top of it. Now, if any of this water entered into a partially exhausted and hot steam-cylinder, it would boil, and prevent the production of a vacuum; it would also cool the cylinder by its evaporation during the descent of the piston. He proposed to remedy this defect by employing wax, tallow, or grease, to lubricate, and keep the piston air-tight. It next occurred to him that, the mouth of the cylinder being open, the air which acted on the piston would cool the cylinder, and condense some steam on its re-admission to this vessel. He therefore proposed to put an air-tight cover upon the cylinder, with a hole and stuffing-box for the piston-rod to slide through in its vertical motion, and *then to admit steam above the piston to act upon it instead of the atmosphere.* BEAUTIFUL INVENTION!—remarkable step in the progress of improvement! Half of the grand work to be effected was now done. Mr. Watt considered that there still remained another source of the destruction of steam, and consequently of its valuable effects, now rendered doubly valuable. This was the cooling of the cylinder itself by the external air, which produced a partial condensation within, whenever the steam entered it, and which would be repeated at every stroke. This he proposed to remedy by an external cylinder containing steam, surrounded by another of wood, or of some other substance which was a slow conductor of heat. By this second grand improvement of the substitution of steam for the atmosphere as the *prime-mover,* the engine became really and truly a *steam-engine;* and, while the power of the mechanism remained the same, the expense of fuel or waste of steam was reduced to nearly a third of its former amount. But it

of valves that suffer any body to go round the channel in one direction only; in these steam-vessels are placed weights, so fitted to them as entirely to fill up a part or portion of their channels, yet rendered capable of moving freely in them by the means hereinafter mentioned or specified. When the steam is admitted in these engines, between the weights and the valves, it acts equally on both, so as to raise the weight to one side of the wheel, and, by the reaction on the valves, successively to give a circular motion to the wheel, the valves opening in the direction in which the weights are pressed, but not in the contrary; as the steam-vessel moves round, it is supplied with steam from the boiler, and that which has performed its office may either be discharged by means of condensers, or into the open air.

"Sixthly. I intend in some cases to apply a degree of cold, not capable of reducing the steam to water, but of contracting it considerably, so that the engines shall be worked by the alternate expansion and contraction of the steam.

"Lastly. Instead of using water to render the piston or other parts of the engines air and steam-tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver, and other metals in their fluid state.

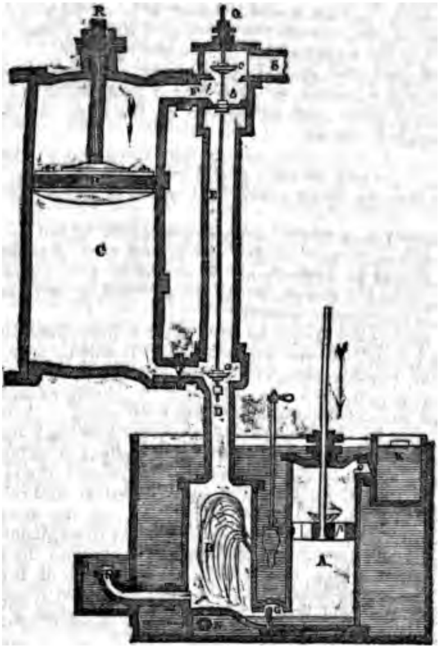
"And the said James Watt, by a memorandum added to the said specification, declared that he did not intend that anything in the fourth article should be understood to extend to any engine where the water to be raised enters the steam-vessel itself, or any vessel having an open communication with it."

From the preceding account of Mr. Watt's first inventions and improvements relating to the steam-engine, it will be seen that this machine consisted of the boiler and steam-cylinder in nearly the same form as they were used by Newcomen and Beighton, excepting that the cylinder was surrounded with a jacket of wood to keep it hot, and the snifting-valve and eduction-pipe were replaced by the air-pump and condenser. In Fig. 16, the principal members of Mr. Watt's *Single-acting Engine*—viz., the cylinder and the condenser, with their appendages, are represented in vertical and medial section. All the parts common to this engine and the atmospheric-engine are omitted, for the sake of simplicity in explanation. By conceiving the piston-rod R, the plug-frame rod O, and the air-pump rod A, attached to the right arm of the working-beam of the engine; and, the rods of the draining-pump and force-pump, with the counter-weight, attached to the left arm of the working-beam, a complete idea will be formed of the whole.

In Fig. 16, C is the steam-cylinder; P the piston; and O D the plug-frame or valve-box, with its steam and eduction-valves. The cylinder has a close air-tight top furnished with a stuffing-box for the piston-rod R, of the piston P, to work through in an air-tight manner; and for this purpose, it must be well turned and polished, and truly cylindrical. The upper end of the piston-rod R is connected with the engine-beam as above mentioned; and by means of the counter-weight at the opposite end of the beam, the piston is moved to the top of the cylinder whenever the pipes communicating with it are all open. S is the pipe which brings the steam from the

boiler, and delivers it through the passage F, into the upper part of the cylinder C, above the piston; this same pipe, also, by its continuation at E, carries the steam through the passage V, into the lower part of the cylinder C; and D is the eduction-pipe which leads down to the condenser B. The valves *a*, *b*, *c*, all open upwards, by means of the plug-tree or valve-rod O D, which opens or closes certain parts

Fig. 16.



WATT'S SINGLE ENGINE APPARATUS.

of the steam-pipe S E, or the eduction-pipe D, when necessary. The valves *a* and *c* are so connected that they both move upwards and downwards at the same time, but the valve *b* moves independently of both. If, now, we conceive the piston P to be at the top of the cylinder, and the valve *c* to be open, while the valve *b* is shut, steam will rush in and enter through the passage F, at the top of the cylinder, and push down the piston P in the direction indicated by the arrow; while all the air contained in the lower part of the cylinder will

escape through the passage V, and the valve *a*, into the condenser B, to be drawn off by the air-pump A. When the piston P has reached the bottom of the cylinder, the valve *c* will be shut, to prevent the entrance of any more steam into the cylinder; and the shutting of the valve *c* will also effect the shutting of the valve *a*, as formerly observed. Immediately after the valves *c* and *a* are shut, the valve *b* will be opened, when there will be a free communication between the upper and lower parts of the cylinder, that is, above and below the piston P, through the pipe E, and the passages F and V; therefore, by the mere effect of the counter-weight on the pump-rod, the piston P will be drawn to the upper part of the cylinder; when all the steam that filled that part will be driven through the open valve *b* and the pipe E, to the lower part of the cylinder; thus producing an equilibrium above and below the piston P, by which it is permitted to ascend, although every part of the cylinder is now completely full of steam.

The piston P having arrived at the top of its stroke, the valve *b* will be shut, and the valves *c* and *a* will be opened. By the valve *a*, an immediate communication is made with the condenser B, and all the steam already in the lower part of the cylinder C will be instantly condensed, and a vacuum created under the piston; at the same time, a new charge of steam will enter the upper part of the cylinder as before, to force the piston downwards, which it does with greater ease than at first, because the condenser has now produced a vacuum in the lower part of the cylinder; and if the steam-gauge of the boiler stand but at 4 inches, which is a very common height in working this description of engine, the steam will operate at the rate of 4 lbs. more on the piston than the atmosphere would do in an open cylinder, and will consequently produce more work. The piston is carried up again by the force of the counter-weight, as soon as the valves *a* and *c* are shut, and *b* opened; thus by maintaining a constant supply of steam in the boiler, and working the valves in regular succession as just described, the motion of the machine may be continued for any required length of time.

The condenser, B, is a cylindric vessel placed below the steam-cylinder C, at any convenient distance, in a large cistern called the *cold-water cistern*, which is supplied with water from a well, and is worked by the engine-beam, like the air-pump. A, the air-pump, is also placed in the cold-water cistern, but without any internal communication with the water it contains. This pump is of the common lift construction, except that its valves, as at *p*, which open as it descends, are made of metal on account of the heat of the water. It is connected by a suction-pipe and *foot-valve*, G, with the bottom of the condenser, B, in order to draw off all the air and water it contains; and this water, being in a hot state when forced up through the valve *p* by the descent of the piston, is delivered into the small cistern, K, called the *hot-water cistern*, through the valve Q. To increase the power of condensation in the condenser, B, it is furnished with a cock, called the *injection-cock*, for admitting a small stream of water into the interior of the condenser in such a manner as to meet the steam before it reaches the bottom; by this means the condensation is

rendered considerably more rapid and effectual. This cock is turned or opened by a long spindle fitted on it, which passes upwards through the floor of the engine-house, and terminates in a handle or lever, which acts as an index, and moves over a small graduated brass circle, to show to what degree the cock is opened, or when it is closed; for, as the condenser is in a state of vacuum when the engine is working, a very small turn of the cock will produce a great difference in the quantity of water discharged into that vessel. The value of this apparatus is so great in some steam-boat engines, that the condensation has been wholly effected by the injection water supplied without a cistern; because, owing to the motion of the sea, it was found impossible to maintain the water in the cold water cistern at the proper height. The vacuum in the condenser B is produced jointly by the condensation of steam and the action of the air-pump A; and as it is important to obtain this vacuum as perfect as possible, so it becomes necessary to have some means of judging of its state, and ascertaining whether the air-pump is in proper repair, and doing its duty. This is done by means of *the barometer*, which is a small air-tight iron tube, proceeding from the upper part of the condenser, and terminating in a glass tube of 32 inches long, fixed against the wall of the engine-house or the pillar of the engine-frame, and filled with quicksilver. The lower or iron part of this tube may be made of an indefinite length, but its upper part, to contain the quicksilver, is bent into the form of the *syphon-gauge* of the air-pump.

The condenser is also furnished with an apparatus called the *blow-valve*, represented at H, which is only necessary at first starting the engine. It consists merely of a conical valve, opening outwards at the end of a pipe leading from the interior of the condenser, at the bottom, and placed in a small detached cistern of cold water. The use of this valve is to produce the first vacuum before the engine begins to move; for while the grease in the piston-packing and stuffing-boxes of the air-pump, condenser, &c., is cold, there is much more friction to overcome than afterwards; and if steam were merely applied on one side of the piston before a vacuum had been produced on the other, it would be almost impossible to put the engine in motion. In order, therefore, to start the engine, the injection-cock of the condenser must be shut, and all the other valves opened at once, a process always provided for in the mechanism of the valves. This being done, and the steam admitted, it will pass not only into the cylinder above the piston, but also below it, and into the condenser at the same time. This must be continued until all the parts in question get sufficiently heated to put them in a proper state for working. The superfluous steam, as these parts become hot, will pass off, and escape through the blow-valve, which is lifted by the force of the steam. This valve is placed under cold water in the cistern H, that it may be condensed as it escapes, and not fill the engine-house with steam. This process is called *blowing through* the engine, and is the cause of the loud noise experienced in the starting of large engines. As soon as the engine is thus properly heated, the side-pipe valve, which permitted the steam to pass into the condenser, must be closed, and the injection-cock opened by turning its handle,

when a vacuum will be instantly formed in the condenser, on the side of the piston opposite to that where the steam is still permitted to act. The piston will now begin to move, and, after one or two strokes, every part of the engine will become properly heated, and continue its motion. The blow-valve does not afterwards interfere with the operation of the engine, being kept constantly shut by the atmospheric pressure. Although the steam in this engine has a double office to perform—namely, that of producing the vacuum, and that of forcing down the piston—yet no more steam is used than was required by the atmospheric engine; for all the time that the piston is moving upwards the boiler is closed, and no steam escapes from it, while the quantity required for the down-stroke is no more than what was formerly required to produce the vacuum, and permit the piston to ascend, while the saving effected by always keeping the cylinder at one uniform temperature, and preventing the waste that used to take in the former engine, rendered it a valuable desideratum for mining and hydraulic purposes. The large engines erected between twenty and thirty years ago in the neighbourhood of London, at the New River, Chelsea, York-buildings, West Middlesex, and Grand Junction Water Works were all constructed on this principle; and most of them had two engines, with cylinders of 54 inches in diameter, and length of stroke eight feet.

It is curious now to look back on the slow progress of the human mind in arriving at one of the noblest of its inventions. All attempts at the construction of a steam-engine *without a piston* were either unavailing or very incomplete. Every engine to be effective and useful, must consist of three principal parts, *a boiler*, *a cylinder with its piston*, and *a condenser*. In Dr. Papin's original project, these three parts were combined in one vessel alone—*the cylinder with its piston*, which contained the water and generated the steam, and thus supplied the place of *a boiler*, and which also acted as *a condenser*, being cooled by removing the fire. In Newcomen's atmospheric engine, the three parts were extended to two vessels, so that the one, *the cylinder with its piston*, was employed also as *a condenser*, being cooled by injection, and the other was *a boiler* alone, connected with the former by means of a pipe. In Mr. Watt's steam-engine the three parts were distinct and separate vessels, but connected by means of pipes; first, *the boiler*; second, *the cylinder and piston*; and third, the *condenser*. Here the utility of the great principle, the division of labour, was manifest even in the application of inert matter to the industrial purposes of mankind. Hence, as Mr. J. Scott Russell observes, "Papin's scheme was possible, but not practicable; Newcomen's engine was practicable, but wasteful; Watt's engine is practical, economical, and complete both in theory and practice; as it renders available all the power of heat which the steam contains."

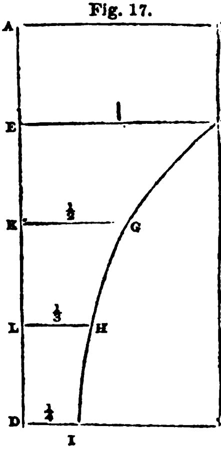
In the atmospheric engine, when working with a load inferior to the whole power of the steam, the force was regulated in order to prevent shocks which might be injurious to the machine, by lessening the *quantity* of injection-water, or by shutting the injection-cock sooner than when working with a full load. Mr. Watt's single acting engine might in some degree be regulated in the same manner; but

it was done more effectually and economically, *first*, by limiting the opening of the regulating-valve which admits the steam above the piston, and allowing it to remain at the same opening during the whole length of the stroke; *secondly*, by allowing this valve to open fully at first, and then shutting it altogether when the piston had descended only part of its stroke; or *lastly*, by employing a throttle-valve, which acting in the same manner as the flood-gate of a mill, admits no more steam than what is requisite to produce the desired power. The second of these methods of regulating the power of the engine forms the basis of what is called the *expansive engine* of Watt, which renders available the greater part of the force with which the steam would rush into empty space, were the piston acted on by the whole of that force, from the bottom to the top of the stroke, through the whole length of the cylinder. This principle, which first occurred to the inventor in 1769, was adopted in an engine at the manufactory in Soho, and in some other places, about the year 1776. It was also adopted at Shadwell water-works in 1778, and was afterwards particularly described in his specification of a patent for several new improvements on steam-engines in 1782. In engines of this construction the steam-valve is always allowed to open fully, as has been remarked; but the pins of the plug-frame are so regulated that the steam-valve shall shut the moment that the piston has descended a certain portion of the stroke —suppose one-fourth, one-third, or one-half of the whole length of the cylinder. As far as either of these limits, the cylinder was occupied by steam as elastic as common air; but this steam, in continuing to press the piston farther down, would necessarily expand, and its elasticity would accordingly diminish; and this could be done to any required extent, as the adjustment can be varied to suit the case by shifting the plug-pins, or altering the mechanism which opens and shuts the valves. But as the pressure on the piston is now continually changing, so is the accelerating force. Its motion, therefore, will no longer be continually accelerated; it will approach much faster to a uniform force; in fact, it may be retarded, because, although the pressure on the piston at the beginning of the stroke may exceed the resistance of the load, yet when the piston is near the bottom the resistance may exceed the pressure. Whatever may be the law by which the pressure on the piston varies, an ingenious mechanic may contrive the connecting machinery in such a way, that the chains or rods at the outer end of the beam shall continually exert the same pressure, or shall vary their pressure according to any law he finds most convenient. It is in this manner that a watch-maker, by the form of the fuzee, produces an equal pressure on the wheelwork of a watch by means of a very unequal action on the main-spring. In like manner, by making the outer arch-heads of the beam such that their sections will represent portions of a proper spiral form, instead of a circle, the force of the beam can be regulated at pleasure. Thus it is plain how much more manageable the single acting expansive engine can be made than the atmospheric engine, and how much more easily its power in various positions can be investigated. Without this knowledge no notion would be formed of what the

former could perform, and this discovery may be deemed one of the greatest importance in the theory of the engine.

It will be proper, at this point in the history of the steam-engine, to explain Mr. Watt's theory of its action by expansion. Let A B C D, Fig. 17, represent a vertical section of the cylinder of an engine, and E F a similar section of the piston. Let it be supposed that the steam was admitted when the piston was in contact with the top of the cylinder, represented by the line A B; and that, as soon as the piston moved into the position represented by E F, by the pressure of the steam, the regulator was shut, and the steam was cut off. The steam which filled the space represented by A E F B, will still continue to press the piston downwards by its expansive force; but in proportion to this expansion its pressure will diminish. Now, if the steam comport itself in such a situation precisely as air does, its force will then be inversely proportional to its rarity or degree of expansion. This property, which steam is considered to possess, may be physically represented by the arc of a curve, F G H I, called the *equilateral hyperbola;* for it is a property of this curve that its abscissæ are to each other inversely as the corresponding ordinates, when the asymptotes are assumed as the co-ordinate axes. Hence, if A D, represents a portion of the asymptote to the curve, and be divided into any number of equal parts, the abscissæ A E, A K, A L, and A D, will then be to each other as the ordinates I D, H L, G K, and E F; and the pressures of the steam at the points E, K, L, and D, will be as the numbers 1, $\frac{1}{2}$, $\frac{1}{3}$, and $\frac{1}{4}$.

Fig. 17.



EXPANSIVE THEORY.

This law, expressed in general terms, amounts to the following theorem: f the expansions, or degrees of rarity, in the steam of a cylinder belonging to a steam-engine, after the steam has been cut off, be represented, at the different points in the descent of the piston, by the abscissæ of an equilateral hyperbola, the pressures of the steam at those points will be represented by their corresponding ordinates; and for this reason, that the relation between the expansions of the steam and its pressures, in such circumstances, is precisely the same as the relation between the abscissæ and the ordinates of the successive points of the curve corresponding to the points in the cylinder, where those expansions take place. According to this view of the subject, the accumulated pressure of the steam, both before and after its expansion, *i.e.*, the point where the steam is cut off, will be obtained from the expression or formula representing the sum of its pressures at every point in the height of the cylinder. Now, if P denote *the pressure on every* square inch of the piston at the moment it *begins to descend, and c* the diameter of the piston, it is plain that

$Pc^2 \times \cdot 7854$ will be the amount of pressure during the descent of the piston from A to E. Moreover, it may easily be shown, by the *integral calculus*, that the amount of the pressure during the descent of the piston from E to D, is $Pc^2 \times \cdot 7854$ multiplied by log. $\frac{L}{b}$, where L denotes the whole length of the stroke, and b the part of it where the steam is cut off, and left to work expansively. Hence, the expression or formula $Pc^2 \times \cdot 7854 \, (1 + \log. \frac{L}{c})$ denotes the sum of the pressures, *before* and *after* the steam has been cut off. The problem, therefore, "To find the whole pressure of the steam in the cylinder of an expansive engine, when the steam has been cut off at a given part of the stroke," will be solved by the following rule: *Divide the whole length of the stroke by the given length of the part at which the steam is to be cut off, and find the Neperian logarithm of the quotient; add unity to this logarithm, and multiply the sum by the product of the pressure on each square inch of the piston at starting, and the area of the piston itself; the result will be the pressure required.* Thus, let the diameter of the piston be 24 inches, and the pressure on every square inch of the piston, before the steam be cut off, 14 pounds; then the product of this pressure, and the area of the piston, which is $24 \times 24 \times \cdot 7854$, will be nearly 6333·5 pounds. Also, let the whole length of the stroke be 6 feet, and let the steam be cut off at a fourth part of the stroke, or 1 feet. Then, the Neperian logarithm of 4 is 1·3862943; therefore, the accumulated pressure is $6333 \times 2.3862943 = 15114$ pounds, nearly. If a table of Neperian logarithms be not at hand, multiply the common logarithm of the number above-mentioned by 2·3026, and it will give the Neperian logarithm, nearly.

In the example just given, the accumulated pressure of the steam, while the piston moves from A B to E F, is $6333 \times 1 = 6333$ pounds. Therefore, the steam, by its expansive pressure through the whole cylinder, adds a pressure of 8781 pounds; for, $15114 - 6333 = 8781$. But if the steam had been freely admitted during the whole descent of the piston, the accumulated pressure would have been $6333 \times 4 = 25332$ pounds. Here Mr. Watt observed a remarkable result. The steam expended in this case would have been *four* times greater than when it was cut off at *one-fourth* of the stroke, and yet the accumulated pressure is *not even twice* as great, being only about *five-thirds*. Hence, *one-fourth* of the steam performs nearly *three-fifths* of the work, and an equal quantity performs more than twice as much work, when thus admitted during one-fourth of the motion. This is curious and important information; and the advantage of this method of working a steam-engine increases in proportion as the steam is sooner stopped; but the increase is not great after the steam is rarefied four times. The reason is, that the curve expressing this increase approaches nearer to the axis, and small additions are made to the area. The expense of such great cylinders is considerable, and may sometimes compensate this advantage.

The following table will show the advantages obtained by working an engine expansively, according to the part of the stroke where the *steam is cut off*. The *first* column shows the fraction of the stroke,

and, consequently, the quantity of steam employed, as compared with the full of the cylinder. The *second* column shows the number of parts in 100 of the whole work which the corresponding quantity of the steam will perform :—

FRACTION OF THE STROKE.		WORK PERFORMED.
One-half	......	85 parts in 100
One-third	......	70 ,,
One-fourth	......	60 ,,
One-fifth	......	52 ,,
One-sixth	......	47 ,,
One-seventh	......	42 ,,
One-eighth	......	38 ,,

"It is very pleasing," says Dr. Robison, "to observe so many unlooked-for advantages resulting from an improvement made with the sole view of lessening the waste of steam by condensation. While this purpose is gained, we learn how to husband the steam, which is not thus wasted. The engine becomes more manageable, and is more easily adapted to every variation in its task, and all its powers are more easily computed." In this calculation it has been asserted that "no allowance has been made for the pressure of the steam decreasing much more rapidly than in proportion to the density, owing to the fall of temperature which necessarily attends such a rapid and great dilatation as the steam has here to undergo, and which must greatly lessen its effect on the engine." This objection would be well-founded if the cylinder itself were liable to the same dilatation as the steam ; but, seeing that the cylinder will necessarily keep up the original heat of the steam, and will readily part with it to the dilated steam, the idea of great diminution of pressure, on account of dilatation alone, appears to be groundless. At the same time it must be admitted that some change in the pressure will take place ; for, unless the dilated steam did really preserve its original temperature, the law of the pressure, being inversely as the expansion, will not hold good. The objection, however, has been met by the important admission that, "unless the expansive system be carried to excess, it is the most advantageous method of using the steam, especially when of high pressure—not only because it renders available most of its force, but because that variable force may be proportioned so as to equalise considerably the action of the engine ; for, at the beginning of each stroke, a great effort is required to overcome the inertia of the beam or of any parts having a corresponding reciprocating motion ; whereas, in the latter part of the stroke, the momentum which those reciprocating parts have acquired is almost sufficient to continue the motion of the engine without the aid of the steam."

Mr. Watt's mining, or "water-commanding engine," as it might now really be denominated, according to the high-flown style of the Marquis of Worcester, was only the precursor of the *double-acting steam-engine*, or the great manufacturing engine of revolution. In considering the nature of his first steam-engine, it had always been matter of regret that one-half of its motion was unaccompanied by any work. It at last occurred to him, that as the steam admitted

above the piston pressed it down, so steam admitted below the piston would press it up with the same force, provided a vacuum were made on its upper side; and that this might be done by connecting the lower end of the cylinder with the boiler, and the upper end with the condenser. SPLENDID ACHIEVEMENT OF GENIUS! Thus was the steam-engine rendered complete, and the noblest mechanical invention that ever entered the mind of man! The grand object of continued vertical motion accompanied by power was now attained; and it only required the application of several pieces of intermediate mechanism to render the steam-engine what it has since become, the most valuable gift of science to the manufactures of this country, and to the commercial intercourse of the human race. The following is a list of the patents given by himself, in which these different new inventions are enrolled.

"PATENT, 25th October, 1781. 'For certain new Methods of applying the Vibrating or Reciprocating Motion of Steam or Fire-Engines to produce a continued Rotative or Circular Motion round an Axis or Centre, and thereby to give Motion to the Wheels of Mills or other Machines.'

"The specification, dated 13th February, 1782, contains a description of five different contrivances of rotative motions."

"PATENT, 12th March, 1782. 'For certain new Improvements upon Steam or Fire-Engines for Raising Water, and other Mechanical Purposes, and certain new Pieces of Mechanism applicable to the same.'

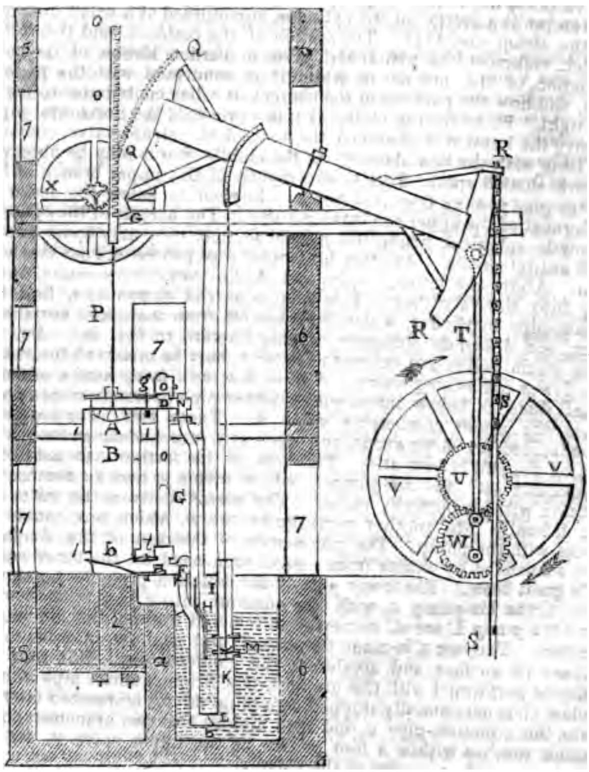
"The specification, dated the 3rd July, 1782, contains, first, the expansive steam-engine, with six different contrivances for equalising the power; second, the double-power steam-engine, in which the steam is alternately applied to press on each side of the piston, while a vacuum is formed on the other; third, a new compound engine, or method of connecting together the cylinders and condensers of two or more distinct engines, so as to make the steam which has been employed to press on the piston of the first, act expansively on the piston of the second, &c., and thus derive an additional power to act either alternately or conjointly with that of the first cylinder; fourth, the application of toothed racks and sectors to the end of the piston or pump-rods, and to the arches of the working-beams, instead of chains; fifth, a new reciprocating, semi-rotative engine, and a new rotative engine or steam-wheel."

"PATENT, 28th April, 1784. 'For certain new Improvements upon Fire and Steam-Engines, and upon Machines worked or moved by the same.'

"The specification, dated the 24th August, 1784, describes, first, a new rotative engine, in which the steam-vessel turns upon a pivot, and is placed in a dense fluid, the resistance of which to the action of the steam, causes the rotative motion; second, methods of causing the piston-rods, pump-rods, and other parts of engines, to move in perpendicular or other straight lines, and to enable the engine to act upon the working-beams both in pushing and pulling—this is now called the *parallel motion,* and three varieties are described; third, improved

methods of applying the steam-engine to work pumps, or other alternating machinery, by making the rods balance each other; fourth, a new method of applying the power of steam-engines to move mills which have many wheels required to move round in concert; fifth, a simplified method of applying the power of steam-engines to the working of heavy hammers or stampers; sixth, a new construction and mode of opening the valves, and an improved working-gear; seventh, a portable steam-engine and machinery for moving wheel-carriages."

Fig. 18.



WATT'S ORIGINAL DOUBLE ACTING STEAM-ENGINE.

"PATENT in 1785. 'For certain newly-improved Methods of Constructing Furnaces, or Fire-places for Heating, Boiling, or Evaporating of Water and other Liquids, which are applicable to Steam-Engines and other Purposes; and also for Heating Melting, and Smelting of Metals and their Ores, whereby greater effects are produced from the Fuel, and the Smoke is in great measure prevented or consumed.'

"The specification is dated the 14th June, 1785."

Mr. Watt's original double-acting engine is represented in Fig. 18, which is copied from the figure which accompanied his specification.

Here BB is a section of the cylinder, surrounded at a small distance by the steam-case IIII. The section of the piston A, and the collar which embraces the piston-rod, gives a distinct notion of its con struction, of the manner in which it is connected with the piston-rod, and how the packing of the piston and collar contributes to make all tight. From the top of the cylinder proceeds the horizontal pipe. Above the letter D is observed the seat of the steam-valve, communicating with the box above it. In the middle of this may be observed a dark-shaded spot. This is the mouth of the upper branch of the steam-pipe coming from the boiler. Beyond D, below the letter N, is the seat of the upper condensing-valve. The bottom of the cylinder is made spherical, fitting the piston, so that they may come nearly into entire contact. Another horizontal pipe proceeds from this bottom. Above the letter E is the seat of the lower steam-valve, open ing into the valve-box. This box is at the extremity of another steam-pipe marked C, which branches off from the upper horizontal part, and descends obliquely, coming forward to the eye. Beyond this steam-valve, and below the letter F, may be observed the seat of the lower condensing-valve. A pipe descends from hence, and at a small distance below unites with another pipe G, which comes down from the upper condensing valve N. These two eduction-pipes thus united go downwards, and open at L into a rectangular box, of which the end is seen at L. This box, at its farther extremity communicates with the air-pump K, whose piston is here represented in section with its butterfly valves. The piston delivers the water and air laterally into another rectangular box M, which box communicates with the pump. The piston-rods of this and of the air-pump are suspended by chains from a small arch-head on the inner arm of the great beam. The lower part of the eduction-pipe, the horizontal box L, the air-pump K, with the communicating box M between it and the pump I, are all immersed in the cold water of the condensing cistern. The box L is made flat, broad, and shallow, in order to increase its surface and accelerate the condensation. But that this may be performed with the greatest expedition, a small pipe H, open below (but occasionally stopped by a plug-valve,) is inserted laterally into the eduction-pipe G, and then divides into two branches, one of which reaches within a foot or two of the upper valve N, and the other approaches as near to the valve F.

As it is *intended by this construction to give the piston a strong impulse in both directions*, it will not be proper to suspend its rod by

a chain from the great beam; for it must not only pull down that end of the beam, but also push it upwards. It may indeed be suspended by double chains, like the pistons of the engines for extinguishing fires; and Mr. Watt has accordingly done so in some of his engines. But in his drawing, from which this figure is copied, he has communicated the force of the piston to the beam by means of a toothed rack oo, which engages or works in the toothed sector QQ on the end of the beam. The reader will understand, without any further explanation, how the impulse given to the piston in either direction is thus transmitted to the beam without diminution. These racks and sectors were very soon laid aside, and a better method, called the parallel motion (hereinafter described) employed instead of them. The fly xx, with its pinion Y, which also works in the toothed arch QQ, may be supposed to be removed for the present, and will be considered afterwards.

We shall take the present opportunity of describing Mr. Watt's method of communicating the force of the steam-engine to any machine of the rotatory kind. V V represents the rim and arms of a very large and heavy metallic fly. On its axis is the concentric toothed wheel U. There is attached to the end of the great beam, a strong and stiff rod T T, to the lower end of which a toothed wheel W is firmly fixed by two bolts, so that it cannot turn round. This wheel is of the same size and in the same vertical plane with the wheel U; and an iron link or strap connects the centres of the two wheels, so that the one cannot quit the other. The engine being in the position represented in the figure, suppose the fly to be turned once round by any external force in the direction of the darts. It is plain that, since the toothed wheels cannot quit each other, being kept together by the link, the inner half (that is, the half next the cylinder) of the wheel U will work on the inner half of the wheel W; so that, at the end of the revolution of the fly, the wheel W must have got to the top of the wheel U, and the outer end of the beam must be raised to its highest position. The next revolution of the fly will bring the wheel W and the beam connected with it to their first positions; and thus every two revolutions of the fly will make a complete period of the beam's reciprocating movements. Now, instead of supposing the fly to drive the beam, let the beam drive the fly. The motions must be perfectly the same, and the ascent or descent of the piston will produce one revolution of the fly.

Mr. Watt gives the following history of this invention:—"I had very early turned my mind to the producing continued motions round an axis; and it will be seen, by reference to my first specification, in 1769, that I there described a steam-wheel, moved by the force of steam acting in a circular channel against a valve on one side, and against a column of mercury or some other fluid metal on the other side. This was executed upon a scale of about six feet diameter at Soho, and worked repeatedly; but was given up, as several practical objections were found to operate against it. Similar objections lay against other rotative engines which had been contrived by myself and others, as well as to the engines producing rotatory motions by means of ratchet-wheels. Having made my reciprocating engines

very regular in their movements, I considered how to produce rotative motions from them in the best manner; and amongst various schemes proposed, none appeared so likely to answer the purpose as the application of the crank in the manner of the common turning lathe (an invention of great merit, of which the humble inventor, and even its era, are unknown). But, as the rotative motion is produced in that machine by the impulse given to the crank in the descent of the foot only, and behoves to be continued in its ascent by the momentum of the wheel which acts as a fly, and being unwilling to load my engine with a fly heavy enough to continue the motion during the ascent of the piston (and even were a counter-weight employed to act during that ascent, of a fly heavy enough to equalise the motion), I proposed to employ two engines acting upon two cranks fixed on the same axis at an angle of 120 degrees to one another, and a weight placed upon the circumference of the fly at the same angle to each of the cranks, by which means the motion might be rendered nearly equal, and a very light fly would only be requisite. This had occurred to me very early, but my attention being fully employed in making and erecting engines for raising water, it remained *in petto* until about the year 1778, when Mr. Wasbrough erected one of his ratchet-wheel engines at Birmingham, the frequent breakages and irregularities of which recalled the subject to my mind, and I proceeded to make a model of my method, which answered my expectations; but having neglected to take out a patent, the invention was communicated by a workman employed to make the model to some of the people about Mr. Wasbrough's engine, and a patent was taken out by them for the application of the crank to steam-engines. This fact the said workman confessed, and the engineer who directed the works acknowledged it, but said, nevertheless, the same idea had occurred to him prior to his hearing of mine, and that he had even made a model of it before that time, which might be a fact, as the application to a single crank was sufficiently obvious. In these circumstances, I thought it better to endeavour to accomplish the same end by other means, than to enter into litigation, and, if successful, by demolishing the patent, to lay the matter open to everybody. Accordingly, in 1781, I invented and took out a patent for several methods of producing rotative motions from reciprocating ones, amongst which was the method of the sun and planet wheels described in the text.

"This contrivance was applied to many engines, and possesses the great advantages of giving a double velocity to the fly; but is perhaps more subject to wear, and to be broken under great strains, than the crank, which is now more commonly used, although it requires a fly-wheel of four times the weight, if fixed upon the first axis. My application of the double engine to these rotative machines rendered unnecessary the counter weight, and produced a more regular motion; *so that, in most of our great manufactories, these engines now supply the place of water, wind, and horse mills; and instead of carrying the work to the power, the prime agent is placed wherever it is most convenient to the manufacturer.*"

Let us now trace the operation of this machine through all its steps.

Recurring to Fig. 18, let us suppose that the lower part of the cylinder BB is exhausted of all elastic fluids; that the upper steam-valve D and the lower eduction-valve F are open, and that the lower steam-valve E and upper eduction-valve N are shut. It is evident that the piston must be pressed towards the bottom of the cylinder, and must pull down the end of the working-beam by means of the toothed rack OO and sector QQ, causing the other end of the beam to urge forward the machinery with which it is connected. When the piston arrives at the bottom of the cylinder, the vales D and F are shut by the plug-frame, and E and N are opened. By this last passage the steam gets into the eduction-pipe, where it meets with the injection water, and is rapidly condensed. The steam from the boiler enters at the same time by E, and pressing on the lower side of the piston, forces it upwards, and by means of the toothed rack OO and toothed sector QQ forces up that end of the working-beam, and causes the other end to urge forward the machinery with which it is connected; and in this manner the operation of the engine may be continued for ever.

The injection water is continually running into the eduction-pipe, because condensation is continually going on, and therefore there is a continual atmospheric pressure to produce a jet. The air which is disengaged from the water, or enters by leaks, is evacuated only during the rise of the piston of the air-pump K.

It is evident that this form of the engine, by maintaining an almost constant and uninterrupted impulsion, is much fitter for driving any machinery of continued motion than any of the former engines, which were inactive during half of their motion. It does not, however, seem to have this superiority when employed to draw water; but it is also fitted for this task. Let the engine be loaded with twice as much as would be proper for it if a single-stroke engine, and let a fly be connected with it. Then it is plain that the power of the engine during the rise of the steam-piston will be accumulated in the fly; and this, in conjunction with the power of the engine during the descent of the steam-piston, will be equal to the whole load of water.

Speaking of the engine just described, Mr. Watt says:—"I do not exactly recollect the date of the invention of the double engine, but a drawing of it is still in my possession, which was produced in the House of Commons when I was soliciting the act of parliament for the prolongation of my patent in 1774-5. Having encountered much difficulty in teaching others the construction and use of the single engine, and in overcoming prejudices, I proceeded no farther in it at that time, nor until, finding myself beset with an host of plagiaries and pirates in 1782, I thought proper to insert it, and some other things, in the patent above-mentioned.

"The mention of the Albion mills induces me to say a few words respecting an establishment so unjustly calumniated in its day, and the premature destruction of which by fire, in 1791, was, not improbably, imputed to design. So far from being, as misrepresented, a monopoly injurious to the public, it was the means of considerably reducing the price of flour while it continued at work.

"*It consisted of two engines*, each of fifty horses power, and twenty *pairs of millstones, of* which twelve or more pairs, with the requisite

machinery for dressing the flour and for other purposes, were generally kept at work. In place of wooden wheels, always subject to frequent derangement, wheels of cast-iron, with the teeth truly formed and finished, and properly proportioned to the work, were here employed, and other machinery, which used to be made of wood, was made of cast-iron, in improved forms; and I believe the work executed here may be said to form the commencement of that system of mill-work which has proved so useful to this country.

"In the construction of that mill-work and machinery, Boulton and Watt derived most valuable assistance from that able mechanician and engineer, Mr. John Rennie, then just entering into business, who assisted in planning them, and under whose direction they were executed.

"The engines and mill-work were contained in a commodious and elegant building, designed and executed under the direction of the late Mr. Samuel Wyatt, architect.

"Though the double engines have been principally applied to rotative motions, yet where mines are very deep, they are advantageously applied to the working of pumps by a reciprocating motion; one set or half of the pump-rods being suspended by means of a sloping rod from the working-beam near the cylinder, and the other half of these rods being suspended directly from the outer end of that beam, so that the ascending motion of the piston pulls up one-half of these rods, and works the pumps belonging to them, and the descending motion of the piston pulls up the other half of the rods, and works their pumps.

"An engine of this construction was erected at Wheal Maid Mine, in Cornwall, in the beginning of 1788, having a cylinder of sixty-three inches diameter, and nine feet stroke; but the stroke in the pumps, which were eighteen inches diameter, was only seven feet. This engine, which at the time it was made, was the most powerful in the world, worked remarkably well, though, like many others in Cornwall, it was loaded with an enormous weight of dry pump-rods.

"In other cases, when it has not been convenient to divide the pump-rods into two sets, the ascending motion of the piston has been employed to raise a weight equal to one-half the column of water in the pumps, which weight came in aid of the power of the engine in the descending stroke of the piston; but the former method is preferable, wherever it can be adopted."

In speaking of the steam and eduction-valves, we said that they were all puppet-valves. Mr. Watt at first employed cocks, and also sliding-valves, such as the regulator or steam-valves in the old engines. But he found them always to lose their tightness after a short time. This is not surprising, when we consider that they are always perfectly dry, and very hot. He was therefore obliged to change them all for the puppet-clacks, which, when truly ground and nicely fitted in their motions at first, are not found to go soon out of order. Other engineers now universally use them in the old form of the steam-engine, without the same reasons, and merely by servile and *ignorant imitation.*

This was the construction of the regulator boxes or nozles which was generally employed by Boulton and Watt at first; but upon the introduction of the double engines, it was somewhat changed, the regulator or valve, which admitted the steam to the cylinder, was placed directly over the exhaustion-valve, which admitted the steam to the condenser.

At a later period, Mr. Murdock contrived another arrangement, which is now generally followed in steam-engines applied to the working pumps, or other reciprocating motions. The regulating-valves are placed one over another, as has just been mentioned; the stems of the steam-regulators are hollow cylinders, through which, and a collar of hemp, the stems of the exhaustion-valves pass upwards air-tight, and these hollow stems of the steam-regulators also pass through stuffing-boxes in the covers of the regulating boxes. In this arrangement the regulators or valves are raised and depressed by means of machinery fixed upon the outside (in place of that described in the inside), and are preferable from their being more easily accessible in case of derangement.

Mr. Murdock also contrived an excellent sliding-valve for the admission of steam into, and its exit from, the cylinder (now very generally used, with some improvements, by Boulton, Watt, and Co., in their rotative engines), for which, along with several other articles, he obtained his Majesty's patent in 1799 (the specification of which has been published in the "Repertory of Arts." vol. xiii.) To the ingenuity of Mr. Murdock are also due many improvements in the manufacture of the engines, and in the machines and tools used for that purpose.

When a person properly skilled in mechanics and chemistry reviews these different forms of Mr. Watt's steam-engine, he will easily perceive them susceptible of many intermediate forms, in which any one or more of the distinguishing improvements may be employed. The first great improvement was the condensation in a separate vessel. This increased the original powers of the engine, giving to the atmospheric pressure and to the counter-weight their full energy; at the same time the waste of steam greatly diminished. The next improvement, by employing the pressure of the steam instead of that of the atmosphere, aimed not only at a still farther diminution of the waste, but was also fertile in advantages, rendering the machine more manageable, and particularly enabling us at all times, and without trouble, to suit the power of the engine to its load of work, however variable and increasing, and brought into view a very interesting proposition in the mechanical theory of the engine, viz., that the whole performance of a given quantity of steam may be augmented by admitting it into the cylinder only during a part of the piston's motion. Mr. Watt has varied the application of this proposition in many ways; and there is nothing about the machine which gives more employment to the sagacity and judgment of the engineer. The third improvement of the double impulse may be considered as the finishing touch given to the engine, and renders it as uniform in its action as any water-wheel.

The only thing that seemed susceptible of considerable improve-

ment was the great beam. The enormous strains exerted on its arms required a proportional strength. This required a vast mass of matter, not less indeed, in an engine with a cylinder of fifty-four inches, than three tons and a half, moving with the velocity of three feet in a second, which must be communicated in about half a second. This mass must be brought into motion from a state of rest, must again be brought to rest, again into motion, and again to rest, to complete the period of a stroke. This consumed much power; and Mr. Watt was not able to load an engine with more than ten or eleven pounds on the inch and preserve a sufficient quantity of motion, so as to make twelve or fifteen eight-feet strokes in a minute.

The difficulty of obtaining timber of sufficient dimensions to form the working-beam of a very powerful engine in one log, early suggested to the constructors of steam-engines the forming them of six or more logs laid flat upon one another, and side to side, and screwed together upon dowells or joggles to prevent them from sliding upon one another; but however well working-beams so constructed have been put together, it has been found that, after they have been some time in use, the straps and bolts by which the logs were connected have gradually got loose, and several bad consequences have ensued. Beams in one solid log were therefore preferred wherever they could be obtained. In small engines Mr. Watt sometimes used cast-iron wheels, or large pulleys, in place of working-beams, and, occasionally, other contrivances. Whenever timber could not be got large enough to form the beams in one piece, Mr. Watt resorted to simple beams braced with iron. But for many years working-beams of timber for engines of every size have been entirely laid aside, and those made of cast-iron have been employed in place of them, whereby the bending, splitting, twisting, dry-rot, &c., to which wood is subject, are completely avoided.

Mr. Watt was, in his labours, latterly associated with the celebrated mechanic and philosopher Mr. Boulton, of Soho, near Birmingham. They shared the royal patent from the beginning; and the alliance was equally honourable and profitable to both individuals. Mr. Watt, speaking of his early labours, says: "The late Dr. Roebuck, of Borrowstoness, a gentleman of much ingenuity and enterprise, was originally associated with me in the profits which might accrue from the patent; but about 1773, he disposed of his interest in it to Mr. Boulton, and both of them, in 1774-5, assisted me in procuring an Act of Parliament for the prolongation of the patent for twenty-five years from that time; and I then commenced a partnership with the latter, which terminated with the exclusive privilege in the year 1800, when I retired from business; but our friendship continued undiminished to the close of his life. As a memorial due to that friendship, I avail myself of this public opportunity of stating that, to his friendly encouragement, to his partiality for scientific improvements, and his ready application of them to the processes of art; to his intimate knowledge of business and manufactures, and to his extended views and liberal spirit of enterprise, must in a great measure be ascribed, whatever success may have attended my exertions."

The advantages derived from the patent-right showed both the superiority of the engine and the liberal minds of the proprietors. They erected the engines at the expense of the employers, or gave working drafts of all the parts, with instructions, by which any resident engineer might execute the work. The employers selected *the best engine of the ordinary kind in the neighbourhood, using the same sort of coals*, compared the quantities of fuel expended by each, and paid to Messrs. Watt and Boulton one-third of the annual savings for a certain term of years. By this plan the patentees were excited to do their utmost to make the engine perfect; and the employer paid in proportion to the advantage he derived from it. Afterwards to avoid disputes and trouble, they fixed certain rates for each sized engine, according to the value and quality of coals in the neighbourhood.

When Boulton and Watt set about the introduction of the rotative steam-engines, to give motion to mill-work, they felt the necessity of adopting some mode of describing the power, which should be easily understood by the persons who were likely to use them. Horses being the power then generally employed to move the machinery in the great breweries and distilleries of the metropolis, where these engines came first into demand, the power of a mill-horse was considered by them to afford an obvious and concise standard of comparison, and one sufficiently definite for the purpose in view. A horse going at the rate of two-and-a-half miles an hour rises a weight of 150 lbs. by a rope passing over a pulley, which is equal to the raising 33,000 pounds one foot high in a minute. This was considered the horse's power; but in calculating the size of the engines, it was judged advisable to make a very ample allowance for the probable case of their not being kept in the best order, and therefore the load was only assumed at about 7 lbs. on the square inch of the piston, although the engines work well to 10 lbs. on the inch, exclusive of their own friction.

The burning of one bushel of good Newcastle or Swansea coals in Mr. Watt's reciprocating engines, working more or less expansively, was found, by the accounts kept at the Cornish mines, to raise from 24 to 32 millions of pounds of water one foot high: the greater or less effect depending upon the state of the engine, its size, and rate of working, and upon the quality of the coal.

In engines upon the rotative double constructions, one having a cylinder of 31¼ inches diameter, and making 17¼ strokes of 7 feet long per minute, called 40 horses' power, meaning the constant exertions of 40 horses (for which purpose, supposing the work to go on night and day, 3 relays, or at least 120 horses, must be kept,) consumed about 4 bushels of good Newcastle coal per hour, or 400 weight of good Wednesbury coal. A rotative double engine, with a cylinder of 23¾ inches in diameter, making 21¼ strokes of 5 feet long per minute, was called 20 horses' power; and an engine, with 17½ inches diameter, making 25 strokes of four feet long per minute, was called 10 horses' power; and the consumption of coals by these was nearly proportioned to that of the 40 horses' power.

A bushel of Newcastle coals, which thus appears to be the con-

sumption of a ten-horse engine for one hour, grinds and dresses about ten bushels, Winchester measure, of wheat.

The quantity of water necessary for injection may be determined on principle for engines having a separate condenser. Having found the contents of the cylinder in cubic feet (that is, the area of the piston multiplied by the length of the stroke increased by one-tenth, to allow for the vacuities at top and bottom through which the piston does not pass), it must be considered that every cubic foot of steam produces about a cubic inch of water when condensed, and contains about as much latent heat as would raise 960 cubic inches of water one degree. This steam must not only be condensed, but must be cooled down to the temperature of the hot well: therefore as many inches of cold water must be employed as will require all this heat to raise it to the temperature of the hot well.

Therefore let c be the quantity of steam to be condensed in cubic feet;
a = the temperature of the cold water (per Fahrenheit);
b = the proposed temperature of the warm water, or hot well;
1172 = the sum of the sensible and latent heats of steam;
x = the cubic inches of cold water required to condense c.
Then $c \times (1172-b) = x \times (b-a)$:

Therefore $c \times \dfrac{1172-b}{b-a} = x$.

Thus, if the proposed temperature of the hot well be 100 deg. (and it should not be higher to obtain a tolerable vacuum in the cylinder), and that of the injection be 50 deg., we have $a = 50$ deg, $b = 100$ deg.; hence $\dfrac{1172-100}{100-50} = 21.44 = x$. That is, for every foot of the capacity of the stroke in the cylinder increased by one-tenth as directed; or, for every cubic inch of water evaporated from the boiler, about 21½ cubic inches of water at 50 deg. will be required to condense the steam.

But as the injection water may not be obtained so cold as 50 deg., and other circumstances may require an allowance, a wine pint of water for every inch boiled off, or for every cubic foot of the contents of the stroke in the cylinder, may be kept in mind as amply sufficient. This greatly exceeds the quantity necessary in a good Newcomen's engine, and by showing the more perfect condensation, points out the superiority of the new engine; for the atmospheric engine, if working to the greatest advantage, should not be loaded to more than 7 pounds upon the inch, whereas Watt's engine bears a load not much less than 11 pounds, exclusive of friction, when making 12 eight-feet strokes per minute.

What has been now said is not a matter of mere curiosity: it affords an exact rule for judging of the good working order of the engine. We can measure with accuracy the water admitted into the boiler during an hour without allowing its surface to rise or fall, and also the water employed for injection. If the last be above the proportion now given (adapted to the temperatures of 50 and 100 deg.), we are

certain that steam is wasted by leaks, or by condensation in some improper place.

It is evident that it is of great importance to have the temperature of the hot well as low as possible, because there always remains steam in the cylinder of the same or rather higher temperature, possessing an elasticity which balances part of the pressure on the oth side of the piston, and thus diminishes the power of the engine. This is clearly seen by the barometer which Mr. Watt applied to his engines, and is a most useful addition to the proprietor. It shows him the state of the vacuum, and, with the height of the mercury in the steam-gauge, points out the real power of the engine.

Mr. Watt found that, with the most judiciously constructed furnaces, it required 8 feet surface of the boiler to be exposed to the action of the fire and flame to boil off a cubic foot of water in an hour, and that a bushel of Newcastle coals so applied will boil off from 8 to 12 cubic feet, and that it required about a cwt. of Wednesbury coals to do the same.

In consequence of the great superiority of Mr. Watt's engines, both with respect to economy and manageableness, they became of most extensive use in every demand of manufacture on a great scale. The greatest mechanical project that ever engaged the attention of man was proposed to be executed by this machine—viz., draining the Haerlem Meer, and even reducing the Zuyder Zee. A considerable engine was, however, erected by them at Mydrecht for draining a large extent of country, in which it was successful. Numberless attempts have been made to improve Mr. Watt's engine, and it would occupy a volume to give an account of them, whilst that account would do no more than indulge curiosity.

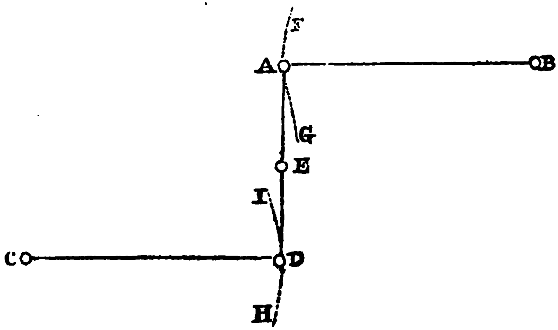
We cannot conclude the history of Mr. Watt's inventions without noticing the ingenious apparatus which he, from time to time, applied to his engine, to render it completely automatic.

The first is the parallel motion, which in the single engines serves in place of chains, and in the double engines supplies the place of the rack and sector. It has been mentioned that the racks and sectors were very subject to wear, and that, when perfect, they did not move with that smoothness that was wished, and to chains there were many objections. It occurred to Mr. Watt that if some mechanism could be devised moving upon centres, which would keep the piston-rods perpendicular, both in pushing and pulling, that a smoother motion would be attained, and, in all probability, that the parts would be less subject to wear. After some consideration, it occurred that if two levers of equal length were placed in the same vertical plane, nearly as shown in Fig. 19, moveable on the centres B and C, and connected by a rod AD, the point E, in the middle of that rod, would describe nearly a straight and perpendicular line, when the ends A and D of the levers, and of that rod, moved in the segments of circle FG and IH, provided the arch FG did not much exceed 40 degrees, and consequently that if the top of the piston-rod were attached to that point E, it would be guided perpendicularly, or nearly so.

It necessarily followed that if for convenience the lever CD (which *represents what he called* the regulating-radius) were made only half

the length of the lever AB (which represents the half-length or radius of the working-beam), a point situated at one-third of the length of the rod AD, from the joint A, would then move in a perpendicular line. These were first ideas; but the parallel motion was soon moulded into

Fig. 19.

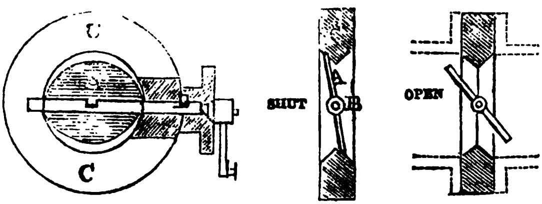


FIRST PARALLEL MOTION.

the form in which it appears in all Boulton and Watt's engines. A patent for the protection of this, and some other of Mr. Watt's inventions, passed the seals in April, 1784, but the invention was made in 1783.

A second article is the method of regulating the speed of the rotative engines, a matter essential to their application to cotton-spinning,

Fig. 20.



THROTTLE-VALVE.

and many other manufactories. It is performed by admitting the steam into the cylinder more or less freely, by means of what is called a Throttle-valve, which is commonly a circular plate of metal, A, *Fig. 21, having* a spindle B fixed across its diameter.

This plate is accurately fitted to an aperture in a metal ring CC, of some thickness, through the edgeway of which the spindle is fitted steam-tight, and the ring is fixed between the two flanches of the joint of the steam-pipe which is next to the cylinder. One end of the spindle, which has a square piece upon it, comes through the ring, and has a spanner fixed upon it, by which it can be turned in either direction. When the valve is parallel to the outsides of the ring, it shuts the opening nearly perfectly; but when its plane lies at an angle with the ring, it admits more or less steam according to the degree it has opened; consequently the piston is acted upon with more or less force. For many purposes, engines are thus regulated by hand at the pleasure of the attendant; but where a regular velocity is required, other means must be applied to open and shut it, without any attention on the part of those who have the care of it. For this purpose Mr. Watt tried various methods, but at last fixed upon what he calls the Governor, consisting of a perpendicular axis, turned by the engine. To a joint near the top of this axis are suspended two iron rods carrying heavy balls of metal at their lower ends, in the nature of pendulums. When this axis is put in motion by the engine, the balls recede from the perpendicular by the centrifugal force, and by means of a combination of levers fixed to their upper end, raise the end of a lever which acts upon the spanner of the throttle-valve, and shuts it more or less according to the speed of the engine, so that as the velocity augments, the valve is shut, until the speed of the engine and the opening of the valve come to a maximum and balance each other. The application of the centrifugal *principle* was not a new invention, but had been applied by others to the regulation of water and windmills; but Mr. Watt improved the mechanism by which it acted upon these machines, and adapted it to his engines.

From the beginning, Mr. Watt applied a gauge to show the height of the water in his little boiler, which consisted of a glass tube communicating at the lower end with the water in the boiler, and at the upper end with the steam contained in it. This gauge was of great use in his experiments, but in practice other methods are adopted. He has always used a barometer to indicate the degree of exhaustion in his engines. Sometimes that instrument is, as usual, a glass tube 33 or 34 inches long, immersed at bottom in a cistern of mercury, and at top communicating by means of a small pipe and cock with the condenser. The oscillations are in a great degree prevented by throttling the passage for the steam by means of the cock.

But as glass tubes were liable to be broken by the workmen, barometers were made of iron tubes, in the form of inverted syphons, one leg about half the length of the other, to the upper end of the long leg a pipe and cock were joined, which communicated with the condenser; a proper quantity of mercury was poured into the short leg of the syphon, which naturally stood level in the two legs. A light float with a slender stem was placed in the short leg, and a scale divided into half-inches applied to it, which (since by the exhaustion *the mercury* rose as much in the long leg as it fell in the short one) *represented inches on* the common barometer.

The steam-gauge is a short glass tube, with its lower end immersed in a cistern of mercury, which is placed within an iron box screwed to the boiler steam-pipe, or to some other part communicating freely with the steam, which, pressing on the surface of the mercury in the cistern, raises the mercury in the tube (which is open to the air at the upper end), and its altitude serves to show the elastic power of the steam over that of the atmosphere. These instruments are of great use, when kept in order, in showing the state of the engine; but are too apt to be put out of order, or allowed to remain in this state. *It is the interest, however, of every owner of an engine to see that they, as well as all other parts of the engine, are carefully attended to.*

The barometer being adapted only to ascertain the degree of exhaustion in the condenser, where its variations were small, the vibrations of the mercury rendered it very difficult, if not impracticable, to ascertain the state of the exhaustion of the cylinder at the different periods of the stroke of the engine; it became, therefore, necessary to contrive an engine for that purpose that should be less subject to vibration, and should show nearly the degree of exhaustion in the cylinder at all periods. The following instrument, called the *indicator*, is found to answer the end sufficiently. A cylinder about an inch in diameter, and six inches long, carefully and truly bored, has a solid piston accurately fitted to it, so as to slide easily by the help of some oil; the stem of the piston is guided in the direction of the axis of the cylinder, so that it may not be subject to jam or cause friction in any part of its motion. The bottom of this cylinder has a cock and a small pipe joined to it, which, having a conical end, may be inserted in a hole drilled in the cylinder of the engine, near one of the ends, so that by opening the small cock a communication may be effected between the inside of the cylinder and the indicator.

The cylinder of the indicator is fastened upon a wooden or metal frame, more than twice its own length; one end of a spiral steel spring, like that of a spring steelyard, is attached to the upper part of the frame, and the other end of the spring is attached to the upper end of the piston-rod of the indicator. The spring is made of such a strength, that when the cylinder of the indicator is perfectly exhausted, the pressure of the atmosphere may force its piston down within an inch of its bottom. An index being fixen to the top of its piston-rod, the point where it stands, when quite exhausted, is marked from an observation of a barometer communicating with the same exhausted vessel, and the scale divided accordingly.

Mr. Watt very early found that, although all kinds of grease would answer when employed to keep the piston tight, yet that beef or mutton tallow were the most proper, and the least liable to decompose; but when cylinders were new or imperfectly bored, the grease soon disappeared, and the piston was left dry; he therefore endeavoured to detain it by thickening it with some substance which would lubricate the cylinder, and not prove decomposable by heat and exhaustion. Black-lead dust seemed a proper substance, and was therefore employed, especially when a cylinder or the packing of the piston was new; but it was found in the end that the black-lead wore the cylinder, though slowly; by more perfect workmanship, cylinders

were at last made so true as not to require it, or at least only for a very short time at first using.

The joints of the cylinder, and other parts of Newcomen's engines, were generally made tight by being screwed together upon rings of lead covered with glazier's putty, a method which was sufficient, as the entry of small quantities of air did not materially affect the working of these engines, where only a very imperfect exhaustion was required. But the contrary being the case in the improved engines, this method would not answer Mr. Watt's purpose. He at first made his joints very true, and screwed them together on pasteboard, softened by soaking in water, which answered tolerably well for a time, but was not sufficiently durable. He therefore endeavoured to find out some more lasting substance; and observing at the iron founderies they filled up flaws by iron borings or fillings, moistened so as ultimately to become hard; he improved upon this plan by mixing the iron borings or filings with a small quantity of sulphur, and a little sal-ammoniac, to which he afterwards added some fine sand from the grindstone troughs. This mixture, being moistened with water and spread upon the joint, heats soon after it is screwed together, becomes hard, and remains good and tight for years, and it contributed in no small degree to the perfection of the engines. Mr. Murdock, much about the same time, without communication with Mr. Watt, made a cement of iron borings and sal-ammoniac, without the sulphur. But the latter substance gives the valuable property of making the cement set immediately.

The act of parliament extending Mr. Watt's exclusive privilege for the improvements secured to him by his first patent, expired in 1800, at which period he retired from business, having for some years before ceased to take an active part. Previous to that time, Messrs. Boulton and Watt, juniors, had been received into the partnership, and had erected extensive works, with improved machinery, for the manufacture of steam-engines; after the death of the original proprietors, the concern was carried on by them, in conjunction with Mr. Southern and Mr. Murdock. Under their management, considerable improvements were made in the execution of the engines, and some advantageous alterations were adopted in the subordinate mechanism and general construction; the use of wood was discontinued, and iron, or, in the fixed parts, stone, or brick-work, substituted in its place; and numbers of expert workmen were trained, so that the engines were executed with a degree of perfection equalling, if not surpassing, the improvements which the increasing wealth and commerce of the country called forth in almost every other art and manufacture.

CHAPTER V.

PROGRESS OF THE STEAM-ENGINE FROM THE END OF THE EIGHTEENTH CENTURY TO THE GREAT EXHIBITION.

After the commencement of the present century, when the steam-engine of Watt had attained a degree of celebrity unparalleled in the history of engineering, a host of imitators and pretended improvers arose to disturb the serenity of the sagacious inventor. He had retired, but he had left his own son, and the son of his liberal patron, as successors to that establishment on which he had conferred both profit and renown. While their progress stood secure, rival engineers did what they could to share the honour and advantage which accrued from the original invention, by attempting to make improvements upon it, or to substitute other engines in which the principles of the first inventor were necessarily involved. In the course of the first moiety of the half century just passed, scarcely a month elapsed in which some new modification of the steam-engine was not proposed. To enter into a detail of all these would be as impossible, as it would be unprofitable to our readers. Some of the more important may be noticed :—

In 1801, a patent was granted to Messrs. Murray and Wood, of Leeds, for their invention of the nozzles or steam-valves, and the method of opening them; but this patent was set aside in 1803, by a writ of *scire facias*, at the instance of Messrs. Boulton and Watt. Mr. J. C. Hornblower, who wrote an account of the steam-engine for the late Dr. Olinthus Gregory, and whose own invention, a patent steam-engine, became the subject of an action at the close of the last century, as an infringement of Mr. Watt's patent, says that "Mr. Watt's engine, as it now stands, is the work of six-and-thirty years, and we may hold it as complete of its kind as it can possibly be. It has exercised the ingenuity of the inventor, besides frequent accessions from the ingenuity of other men: various pretensions and conceits, no doubt, will abound to rival its excellency, and time only, the arbiter of human affairs, will determine their fate. We would rather see a laudable competition prevail to simplify its parts, without affecting the principle, either by reducing their number, or by dispensing with their costly finish, or both, so that it may come within the compass of the middle ranks as well as the more opulent; and the man who sets the example will deserve well of his country."

In February, 1810, Mr. R. Witty took out a patent for rotative steam-engines, the revolving motion of which was effected by weights alternately *drawn to* and driven from a centre, round which a working

cylinder or cylinders revolved: and to the opposite ends of the piston rod or rods, that passed through the said cylinder or cylinders, the weights were attached. Improvements on these engines, for which a patent was taken in October, 1811, Mr. Witty states to consist in making the piston draw or force round the machinery to be worked by it, while itself moves both in a rectilinear and rotatory direction in a cylinder or steam vessel; which also "revolves upon an axis," placed either in a horizontal, vertical, or oblique position. The mechanical contrivances by which this is effected are of various kinds, which cause the power of the piston to draw or force the cylinder round; and move the mill-work, or machinery, which is attached to the engine, by the revolution of the axis or shaft of the revolving cylinder, or by the piston rod being made to act upon a wheel, or other contrivance, upon a separate axis or shaft, fixed or otherwise, as occasion may require.

To admit the action of the steam, and of the condenser, in the revolving cylinder, its axis is bored lengthwise in two places, so as to form two passages, each of which communicates by lateral pipes with the end of the cylinder opposite to the side of the axis in which it lies; the extremity of this perforated axis is formed of a conical shape, and turns in a box made to fit it, in the same manner as the revolving part of a common cock turns in its barrels; from the upper part of this box a pipe passes to the steam boiler, and from the lower part another pipe proceeds to the condenser, and lateral apertures are made through the sides of the axle to the two passages within it before-mentioned, which, as the axle turns, alternately communicate with the steam pipe, and the pipe of the condenser in the box, in the same way as a cock with two ways acts; and indeed this part of the engine is on the same principle. The axle projects through the box, and has a crank at its end, by which it works the air-pump of the condenser.

Several principles are mentioned by the patentee, on which the cylinder, prepared as described, can force itself round; which are all of the nature of crank or cardioid motions; both of which, however, may be referred to one source, as they are caused by an apparatus made to protrude and retract alternately between two centres, one of which revolves, and the other is fixed. The first of these principles stated by the patentee (which he calls a cardioid motion, though it is more properly a crank motion), effects the rotatory movement by the action of a moving groove on a fixed centre; this groove is placed at right angles to the cylinder, in a frame that is connected with piston-rods proceeding from the opposite ends of the cylinder, and of course partakes of their alternating motion.

The second principle consists of the operation of the ends of piston-rods, proceeding from the opposite extremities of the cylinder, on the outside of the rim of a large wheel, whose centre is placed at the distance of about half the stroke of the piston from the axis of the cylinder. The rim of the wheel projects so as to extend to the line of the piston-rods, which are bent round to support friction-wheels outside it, that alternately come in contact with steps on the rim, and by them force round the wheel, by a cardioid motion; or, in other words,

by a motion similar to that which levers would cause, when made to press alternately on the outside of a heart-wheel.

The third principle is a variety of the second, and consists in making the large wheel before-mentioned revolve on a ring, supported by friction-wheels, which includes within its circumference the axle of the revolving cylinder. A species of this last mode is mentioned by the patentee, that deserves particular notice, in which the ring is large enough to include within it the cylinder and protruded piston-rods, and is to be placed in the plane of the piston-rods, and at right angles to the axis of the cylinder.

The fourth principle consists in the action of the piston-rods, arranged, as first mentioned, against the inside of a heart-shaped ring, placed vertically with its apex downwards; one-half of this ring is moveable outwards by being suspended from a hinge at its upper end. The axis of the revolving cylinder is placed in one of the centres of this cardioid-ring; and the ends of the piston-rods, furnished with friction-wheels, press alternately on the fixed and on the moveable sides of the ring, and thus produce the rotative motion.

A fifth mode, mentioned by the patentee as a variety of the first, deserves to be noticed by itself for its greater simplicity: it consists of a crank a quarter the length of the stroke, or a fixed centre placed at that distance from the axis of the cylinder, from which a rod passes to the top of the piston-rod. In this method, and also in the first, a strong iron knee proceeds from the fixed centre to support the gudgeon-end of the axis of the revolving cylinder, or that end which is opposite to its perforated extremity. The end of this knee nearest the fixed centre is driven tight into a piece of cast-iron and keyed fast; this piece is bolted down to a beam of wood that supports it. The fixed centre lies between the angle of this knee and its support.

The advantages of steam-engines, constructed on these principles, over common engines, the patentee states to consist in saving the power lost in the motion of heavy engine-beams, parallel apparatus, valves, hand-gear for moving valves, and plug-frames, none of which are used in his engines; and in the great simplification of machinery, which arises from their removal. The patentee also states, that the ponderous fly-wheel used to regulate the motion in other engines, may in his, be in a great measure dispensed with. The editor of the "Retrospect," from the thirty-second number of which the preceding account of Mr. Witty's contrivances is taken, adds, "When any good method is adopted for preventing the tendency to bend the piston, which an arm at right angles used to force round the engine would occasion, in the manner before explained, then the fifth or last method described would seem to be preferable to most of the others, on account of its greater simplicity, and its having less friction than them. On the contrary, the method in which the grooved frame is used seems the worst, on account of the binding, or increased friction, these grooves acted on by oblique impulses always undergo, especially when the degree of the obliquity approaches so very near a direction perpendicular to the groove, as it does on this occasion; and this, added to the defect before stated, would occasion a very great waste of the force of the engine.

Of all the methods, however, in the state in which they are described by the patentee, those two, in each of which the cylinder revolves within a ring that surrounds it in the plane of the piston-rod, at right angles to the axis of the revolving cylinder, appear the most advantageous; because in them, less of the force is lost in oblique movements, and the piston-rods suffer no injury from any part of the machinery tending to produce lateral impulses. Of these two methods, that with the revolving ring appears to be preferable, from its causing less friction, and producing a more free motion; and as the revolving ring might be likewise made to perform the office of a fly-wheel, it would also be more simple. A mode (not mentioned by the patentee) of applying the smaller ring, that extends only far enough to include the axis of the cylinder, and is described first in the account of the third principle of the patent, seems also preferable to the fixed ring, and nearly if not fully equal to the revolving ring, from the simplicity of construction of which it renders the engine capable.

The advantages stated by the patentee, that engines on these principles possess in comparison with others, seem in most respects justly represented; but, on the other hand, it must be observed that there is much more force lost, in even the best of the methods proposed, from the obliquity of the impulse of the moving power to the motion produced, than in the beam-engine and crank; as the latter acts in two points of the revolution at right angles to the crank, or in the direction of the motion produced, which is the most advantageous direction; while in none of the plans proposed by the patentee does the impulse come much nearer the direction of the produced motion, than what would form with it an angle of forty-five degrees.

We must differ from the patentee also, as to the capability which he supposes his engines afford of dispensing with fly-wheels; thinking, on the contrary, that from the great variation of the force producing the rotary motion, in various parts of the revolution (on account of the great difference in the obliquity of its direction) the fly-wheel would be absolutely necessary to produce equitable rotative motion in them. But notwithstanding that some loss of force would be caused by the obliquity of the impulse to the direction of the motion (as before mentioned), we think that very useful and powerful engines may be formed on the principles invented by the patentee, when they obtained those modifications, which practice and experience in constructing them will point out; and that next to Mr. Mead's plan for a rotative steam-engine, these of the patentee are by far the most ingenious yet laid before the public. We also think, that in point of simplicity, and in the facility of their being kept in order, and having the stuffing kept tight, and renewed when wanted, they are superior to Mr. Mead's engine: and that the species of them which revolves with a simple crank motion, and that with the larger outside revolving ring, if not some of the other kinds, may be afforded at a considerably lower price than Mr. Mead's; or, when the mode of making them is brought to perfection, than most other steam-engines, on account of the number of parts and the quantity of framing used in other engines, that may be omitted in their construction.

In the construction and application of the steam-engine as at present employed in the arts and manufactures, in the draining of mines, and in locomotion by sea and land, we find the practical development of a great number of the most important principles of mechanical and chemical philosophy. Discoveries in these sciences, and in the arts dependent on them, have uniformly, steadily, and progressively led to improvements, of great and incalculable value, in the theory and practice of this wonderful machine. By these improvements, the wealth and the resources of the country have been increased a thousand fold; the comforts and the luxuries of life have been supplied, with a rapidity and to an extent unknown in former ages of the world; and the inhabitants of the most distant places of the globe, have been brought into a closer contact and into a more immediate neighbourhood, than the brightest anticipations of poets, or the boldest conjectures of philosophers ever divined. Future improvements will inevitably produce greater results; nor will it be long ere the happy prediction of ancient prophecy, which is hourly speeding to its accomplishment, be fulfilled in its widest and noblest meaning: "Many shall run to and fro, and knowledge shall be increased." To considerations of the preceding description, must be traced, that universal and unfailing interest invariably manifested by the public mind, at the exhibition of every new and successful appplication of steam power. Hence arises the great encouragement held out to modern ingenuity, for every useful addition to its inexhaustible resources; every real simplification of its complex machinery; and, every possible reduction of its enormous expense. The great number of letters patent which have been granted by the British government, since the time of Watt, for inventions and improvements more or less connected with the steam-engine, is a fact which alone sufficiently demonstrates the increasing importance attached to it in this country; inasmuch as, from documents lying before us, it appears that not less than five hundred of these have been enrolled in the patent office, within a period commensurate with the usual limit of the duration of human life: a period, during which the British empire rose to a height of prosperity without a parallel in the history of nations, and withstood the shock of a series of political convulsions which changed the face of Europe.

The economy of the steam-engine, in its present improved state, requires a thorough acquaintance with the nature and properties of fuel, water, air and steam; the doctrines of heat, combustion, expansion, and condensation; the effects of atmospheric pressure; the force of steam generated at different temperatures and possessing different degrees of elasticity; the consequences arising from the formation of a complete or partial vacuum; the strength of materials to resist intense heat and pressure: the proportions of the different parts of engines of various kinds; and, in short, the general principles of mechanics and of chemistry, and their application to all the multifarious and diversified purposes of human industry and ingenuity, as exemplified in the history and operations of steam power. Professor Moseley of King's College, London, a gentleman to whom we are indebted for some ingenious and original propositions in the science of

mechanics, particularly relating to the theory of the arch, states in a work lately published, that there is very great difficulty in determining the elasticity of the steam in the cylinder of a steam-engine, and its actual pressure upon the piston. The reasons he assigns may be stated as follows: although the steam gauge determines the elasticity of the steam in the *boiler*, under all circumstances, with sufficient accuracy; yet the elasticity of the steam in the cylinder is not the same as that in the boiler; the former being modified by the contraction, retardation, and refrigeration of the steam in its passage through the steam-pipes, by its expansion and cooling in the cylinder, and by the variable resistance of the piston. The determination of all these conditions is a problem of great difficulty, and hitherto an *unsolved* problem of practical mechanics.

With regard to the indicator, the usual apparatus employed for determining the elasticity of the steam in the cylinder, it is considered to be too imperfect, in its present state, to be employed as a sure guide in forming a correct estimate of that elasticity. A mean of its indications is only an approximation to the mean elasticity of the steam in the cylinder, or mean pressure upon the piston; and this, especially when the steam is worked expansively, requires too many corrections for retarding causes, and too nice a calculation for ordinary practice, to render it sufficiently available to the engineer in ascertaining the power of his engine. No doubt, however, need be entertained that, ere long, some improvement will be made in this apparatus, or its use superseded by some other invention, which will remove the defects still existing in the theory of this department of the steam-engine. Some experiments on this subject were recently made in Cornwall, with a view to the determination of the quantity of steam employed, and the mode of its distribution on the working stroke; the duty performed with a given quantity of fuel; and the work accomplished for a certain expense. The result of these experiments with the indicator, which are detailed in the second volume of the "Transactions of the Institution of Civil Engineers," art. V., show that, independently of the pressure of the steam, part of the stroke is performed by virtue of the momentum acquired by the engine in the early part of the working stroke; and that there is a difference between the estimate of this part as obtained by the indicator, and as ascertained by the quantity of water evaporated, which it is difficult to account for satisfactorily. Notwithstanding this difference, still the main fact appears to be established beyond a doubt, by these experiments; so that, here, we have a new element to determine correctly, before we can arrive at the true theory of the working power of a steam-engine. Again, with respect to the *duty* performed with a given quantity of fuel, or the number of pounds raised one foot high by the power of the steam generated by the combustion of that fuel, the results of the experiments detailed in the article referred to, show that the average duty of three engines is about 70 millions of lbs. raised one foot high by the consumption of one bushel or 84 lbs. of coals. Lastly, the work accomplished for a *certain expense—say one farthing*, was about 1000 tons, or more than *two millions of lbs.* raised one foot high. This extraordinary duty

obtained from the Cornish engines at so small an expense, has led to serious doubts among engineers in London and other parts of the country as to the accuracy of the reports in which the facts are detailed. Accordingly, in the very same volume of the "Transactions" already cited, we find a paper, art. III., in which the author not only denies that engines working on the expansive principle can produce such remarkable effects, but he endeavours to prove that unless the known laws of nature respecting heat, fuel, steam, and atmospheric pressure be altered, it is impossible that a greater amount of duty can ever be obtained from an engine, than about 44½ millions of lbs. raised one foot high by the consumption of one bushel of coals, making no allowance for friction, loss of heat, imperfect condensation, or any other cause tending to diminish the full effect of the power of steam.

In this paper, the advantages arising from working steam expansively, by cutting it off at a certain part of the stroke, appears to have been entirely overlooked—a circumstance which is the more remarkable, when it is considered that in the same volume, and within a few pages of each other, facts completely contrary to this theory are detailed in a way sufficient to convince the most sceptical of their perfect fairness and accuracy. In a paper, art. VI., of the same volume, on the effective power of the high pressure expansive condensing engines in use in some of the Cornish mines, the duty of one of these engines, at the Holmbush Mines, near Callington, after the most careful trial, is reported to be about 118 millions of lbs. raised one foot high, by the consumption of a Cornish bushel of coals, which weighs 94 lbs. In this engine, the steam was cut off at one-sixth of the stroke; it entered the cylinder at a pressure of about three atmospheres, or exactly 43¼ lbs. (making an allowance of 1¾ lbs. for imperfect vacuum), and completed the stroke at a pressure of about half an atmosphere, or exactly 7.2 lbs. By taking the pressure of the steam at each successive sixth of the stroke, and finding the mean of these pressures, which is about 17.66 lbs., the effect due to the whole power of the steam is calculated at about 212 millions of lbs. raised one foot high, by the consumption of a Cornish bushel of coals. For, the diameter of the cylinder being 50 inches, the length of stroke 9 feet 1 inch, and the number of strokes during the consumption of the fuel 672, we have, by the common rule, $50 \times 50 \times .7854 \times 17.66 \times 672 \times 9\frac{1}{12} = 211658702$ lbs. raised one foot high for the total effect of the steam. Hence, as the duty was found to be 118 millions, the difference between this and the total effect, that is, about 94 millions of lbs. raised one foot high is the amount of resistance due to the friction of the machinery, a quantity amounting nearly to the half of the whole power of the steam. The principle of this calculation, though perhaps sufficient for practical purposes, is not strictly correct, for it supposes the pressure of the steam to be uniform during each sixth of the stroke, which is not the case, as it *gradually* diminishes according to a certain law. This law, which was known to James Watt, and was mathematically investigated by Dr. Robison, shows that when the steam is cut off at one-sixth of the stroke, the

power to the effect of the steam as ascertained in the preceding article, we have 3 : 1 : : 177 millions : 59 millions; and consequently, $177 + 59 = 236$ millions of lbs. raised one foot high, the total effect of the steam when worked expansively, making due allowance for the momentum acquired by the mass of machinery put in motion by the steam. This result differs so little from that obtained before, that the method employed in arriving at it, amounts to an independent demonstration of the fact of the influence of momentum, developed by the experiments referred to. Such are the effects due to the careful and economical management of steam as applied to mining purposes in Great Britain; we shall see immediately that they are far beyond the anticipations of even our best writers on the subject.

It may be objected to our remarks in a preceding paragraph, that the law which supposes the pressure of steam when cut off from the boiler to vary inversely as the volume or as the expansion, is only true while the temperature is invariable; and that since the temperature is lowered by expansion, a corresponding diminution of pressure will arise from this cause, as well as from the former. Admitting this fact, the power of the engine as calculated in that article, will be diminished only by about a ninth part. For, the pressure at which the stroke was commenced being about six times the pressure at which it was completed, it follows, that if the temperature of the steam had remained unchanged during its expansion in the cylinder, its volume would have been increased about six times. Now, from the table of the volume of steam generated under different pressures compared with that of the water which produced it, calculated by the Comte de Pambour, we find that the volume of steam generated at a pressure of 43 lbs. per square inch is 634, and of steam at 7 lbs. per square inch is 3,380. But $634 \times 6 = 3{,}804$, which is greater than 3,380, by about a ninth part of itself. Deducting therefore, a ninth part of 241 millions of lbs. raised one foot high, from itself, we have 214 millions of lbs. raised one foot high for the exact power of the Holmbush Mines' engine. These remarks apply with equal force to the result of our preceding calculations, which is, in like manner, reduced to 210 millions of lbs. raised one foot high. These results differ very little from that obtained by the more practical but less approximate mode of calculation; and taking friction, and other causes of difference into consideration, they must be reckoned not only very close approximations to the truth as respects the power of the steam developed by the Holmbush Mines' engine, but quite sufficient to demonstrate the fallacy of the arguments employed by those who would deny the accuracy of the reports concerning the duty of the Cornish engines. The gradual improvement which has been made in the steam-engine in Cornwall, in the course of 66 years, will be rendered evident by the following table extracted from the 2nd vol. of the "Transactions of the Institution of Civil Engineers," art. VI.; the third column has been added for the sake of comparison with other results of the power of steam.

Date.	No. of lbs. raised one foot high, by the consumption of 94 lbs. of coals.	No. of lbs. raised one foot high, by the consumption of 84 lbs. of coals.	No. of lbs. of coal per hour for each horse's power.
1769	5,590,000	5,000,000	33.33
1772	9,450,000	8,445,000	19.17
1786—1800	20,000,000	18,000,000	9.30
1813	28,000,000	25,000,000	6.64
1814	34,000,000	30,400,000	5.47
1815	50,000,000	44,700,000	3.72
1825	54,000,000	48,255,000	3.44
1827	62,000,000	55,400,000	3.00
1828	80,000,000	71,500,000	2.32
1834	90,000,000	80,428,000	2.06
1835	97,000,000	86,700,000	1.91
1836	125,000,000	112,000,000	1.48

From the last line of this table, we find that the reported duty of the Fowey Consols, one of the Cornish engines, is still greater than that of the Holmbush Mines' engine, which has been under our consideration in the preceding remarks. The author of the able article, No. XI., in the 1st. vol. of the "Transactions" above cited, states that this duty was performed at a public trial of the Fowey Consolidated Mines' engine; that this is the greatest performance of any engine; and, that the engineers, Messrs. Petherick and West, cannot fail to receive the credit they so richly merit. A march of improvement which has nearly cubed the duty of the steam-engine, where one million of lbs. raised one foot high is the unit, in the course of little more than half a century, or at most a period only surpassing the grand climacteric of man, must indeed be classed among those achievements of our race, which reflect the highest honour on the industry, ingenuity, and skill of the inventors, and which confer the noblest and most substantial benefits in a practical and commercial point of view, on the nation to which they belong.

Notwithstanding the important information we have thus gained by the publication of the monthly reports on the working of the Cornish engines, and more recently, by that of the papers on the same subject in the "Transactions of the Institution of Civil Engineers," it is remarkable that so little is yet known of the true theoretical principles of the steam-engine. The effect due to momentum has, as we have seen in the preceding pages, scarcely ever been noticed, or if noticed, it has never yet been properly estimated, although it is manifest that this effect must, in large engines worked on the expansive principle, increase the power of steam by a very considerable per centage, varying, of course, with the pressure of the steam, the length of the stroke, and the fraction of the stroke at which the steam is cut off. In the case of the Holmbush Mines' engine, this effect amounts to nearly *35 per cent.* of the effect due to the steam alone. We shall

would not have been materially curtailed of its present efficiency. It is a remarkable fact that the steam-engine has scarcely received any very valuable improvement since his time. He, in fact, rendered it a machine nearly perfect. The testimony of Mr. Farey upon this subject is explicit, and must be conclusive on the subject with every one who has the means of ascertaining the very high estimation to which the knowledge and practical skill of that excellent writer on the steam-engine most justly entitle him. "It is a circumstance," says Mr. Farey, "highly creditable to Mr. Watt's character, both as an original inventor and as a practical engineer, that his first double-revolving engine, which he made in 1787, at the Albion Mills, performed quite as well as any engine which has since been constructed to employ steam on the same principles. Some important improvements have been made in the construction of modern engines by substituting cast-iron and stone-work in the place of wood, and by putting the parts together in more substantial modes; but all those essential forms and proportions which affect the performance of the machine were so ascertained by the first inventor, that no improvement has been since made in them, and every departure from those forms and proportions has impaired the performance in a greater or less degree. In the specifications of Mr. Watt's patents are included various inventions which have been brought forward by others as new at more recent dates; as, for instance, the direct acting steam-hammer patented in 1806 by Mr. Deverell, and again in 1843 by Mr. Nasmyth, who has no small merit in having put it in practice on a grand scale and with great success, both as a forge-hammer and also as a pile-driver. In simplicity, docility, and efficiency, it greatly excels any former methods of moving hammers by steam.

Of modern steam-engines there are two distinct species—the high-pressure and low-pressure engines. The former is simple, light, and of few parts, generally used for locomotive engines, steam-carriages, steam-vessels of a light and rapid construction, and such other purposes as require portability or cheapness. The latter is more complex, but more effective; more expensive in original construction, but more durable and more economical in consumption of fuel. The first is more commonly used in America, the latter in this country. The high-pressure engine is sometimes also called the non-condensing steam-engine, to distinguish it from the low-pressure engine, which is also called the condensing steam-engine; but there is sometimes a combination effected of some of the parts and principles of both these species, in what is called a high-pressure condensing-engine, by which, for certain purposes, the peculiar merits of both species are combined in the same machine. Of these two sorts of steam-engine, it is remarkable that the more elementary and simple—that which is the more easily conceived and understood—was not brought into practical use until long after the other kind had been very extensively used and made known by its inventor.

The high-pressure or non-condensing engine consists of *two* principal members, the *generator* or *boiler* and working *cylinder*, each *with sundry appendages.* The low-pressure or condensing steam-

engine consists of *three* principal members, the *generator*, *cylinder*, and *refrigerator* or *condenser*, each with sundry appendages. The generator and working cylinder, with their appendages, are nearly the same in both kinds of steam-engine, the presence of a condenser or refrigerator forming the principal and almost only distinction of the second species. By this second species the steam is returned into its first state of water, thereby effecting a saving of heat and of mechanical power; whereas, in the first form of engine, the steam, before spending nearly all its power, is discharged into the open air as useless—a process which can only be advisable in circumstances where the labour and apparatus for condensing would cost more money, and cause more inconvenience than would counterbalance the loss of fuel and heat and power.

Engineers are in the habit of reckoning the high-pressure of steam by a very simple expedient. They place a weight upon a hole on the top of the boiler. This hole being square, and an inch in length and breadth, and the weight being one pound when the steam is strong enough just to blow the weight off the hole, they call that *steam of an elastic force equal to one pound on the square inch*. They then place a weight of two pounds upon this hole of a square inch, and increase the heat until the steam just blows it off, and that is called *steam of the pressure of two pounds on the square inch*. And, in like manner, when steam is confined and heated until it acquire force enough to blow weights of three, four, five, fifteen, or fifty pounds off an aperture of just a square inch in extent, that is technically called *steam of the elastic pressure of three, four, fifteen, and fifty pounds on the square inch*, over and above the pressure of the atmosphere. It is difficult to say whether there be any limit to the elastic force which steam may acquire from increased temperature and confinement. It is known to be even as powerfully elastic as gunpowder, and pressures of one thousand pounds an inch have been produced. The pressures generally adopted for high-pressure engines are from fifteen to one hundred and twenty pounds on the inch above that of the atmosphere. Of course, when there is a given pressure on any one inch of the surface of a boiler, there will be the same on every other inch of it: and if the aperture under the weight be any number of times greater than one inch, it will just require so much the more weight to keep it closed. The standard by which the pressure is reckoned and calculated is, however, always the square inch.

By placing a moveable weight, called a *safety-valve*, on an aperture of given size in this manner, the engineer not only ascertains the amount of the elastic force of the steam tending to burst the boiler, but also constructs a valve by which to avert the danger of such an explosion. Now a given weight of lead or iron laid on a hole in the top of a boiler, so as to close it, is a sufficient and common form of safety-valve; for whenever the pressure of the steam becomes sufficient to raise the weight, it escapes through the opening into the air without doing any mischief. A large weight of lead, simply placed on the opening, is a very common and simple mode of providing for the safety of the apparatus. But this plan becomes inconvenient when the pressure and weight are great, because it is then so high as to be

unsteady; and, in order to remedy the inconvenience, what is called a *valve* is used, distinct from, and in addition to, the weight. A valve-seat, formed of cast brass, is fixed in the aperture, and is accurately fitted by the conical valve itself, the edges of which are carefully turned and tapered, so as to fit the neck of the valve-seat, and ground in its place to be perfectly steam-tight. A spindle portrudes downwards from the valve through a guide which keeps it in a straight line, and prevents it from falling on one side of the valve after having been raised. This same spindle, rising upwards, carries upon a cross-bar a series of large cylindrical weights, which may be increased or diminished in number as the case may require. It is a practical fault of this valve that the tall erect spindle may easily become bent or injured by accident, and also that the weight upon it may too easily be handled, so as wantonly to be increased; hence, a safety-valve, with an internal weight, has been contrived. A conical valve is placed in its seat in every respect as formerly, only the spindle does not rise up, but hangs down among the steam, terminating in a chain and weight.

In all these modifications the weight on the safety-valve becomes large and cumbrous, when the pressure is great; and in such the use of the lever safety-valve invented by Dr. Papin is resorted to. Another form of valve was used by Mr. Southern for his delicate experiments on high-pressure steam. The cylinder of the valve-seat used in the former figures is prolonged upwards, so as to form a vertical cylinder or tube, in which a plug of metal is exactly fitted. This plug is ground with great care, so as to move freely but steam-tight in the cylinder; and a rod from the cylinder passes up through a hole in the top, and is kept down by a lever and weight. A hole in the cylinder allows the steam to escape whenever the pressure on the valve upwards exceeds the pressure of the levers and weights in the opposite direction. The indications of this instrument are found to be very precise. Another species of safety-valve has of late years come into use, called the spring-valve. It is of two kinds, with a lever and without it. That without the lever is a series of bent springs, placed alternately in opposite directions in a square frame, and forced down upon the valve by a cross-bar, a small screw adjusting the pressure by compressing or releasing the spring. The other form of spring safety-valve interposes a lever between the safety-valve and the spring. These two species of safety-valve are used in locomotive steam-engines.

The pressure of steam in a boiler is indicated by what is called a *mercurial gauge*, communicating with the boiler. Mercury is poured into a bent tube, one end of which springs from the boiler, and the other end is exposed to the air, so that the steam by its pressure raises the mercury in the straight limb of the tube to a height above the level proportioned to that pressure. From calculating the weight of mercury, it is reckoned that, for every pound of pressure of the steam in the boiler, there is an inch of mercury raised in the tube. Sometimes, also, a small float of iron is placed on the mercury, which, carrying a slender rod with an index, points to the elevation of the mercury on a scale above the gauge. It is evident that this instru-

ment also acts as a safety-valve, inasmuch as the steam, when too strong, must force the mercury entirely over the top of the tube, and make its escape. A double pipe, on a larger scale, with water in it instead of mercury, would answer equally well, only the water would rise one foot and an inch for every pound of pressure of steam in the leg of the double tube, and twice that quantity if the tube were single, which would give a scale of 16½ feet in a double tube, or 33 feet in a single tube, as the column of water raised above the level by a pressure of 15 lbs. on the square inch.

It is convenient to reckon the pressure of steam in larger numbers than pounds, and the quantity that has been fixed is a weight of 15 lbs., or a stone weight, per square inch; and to this weight the name of an atmosphere of pressure has been given, simply because the common atmosphere of air presses on all bodies with a weight of nearly 15 lbs. on the square inch. Thus steam having a pressure of 15 lbs. on the square inch is called high-pressure steam of the elastic force or strength of one atmosphere; and that having a pressure of 30 lbs. is said to have an elastic force of two atmospheres; 45 lbs. of three atmospheres, &c. Sometimes, however, a rather different mode is adopted, and the common steam of boiling water, which exerts no further pressure than merely to balance the atmosphere, is called steam of one atmosphere, and in this case the elastic force which has been called one atmosphere would be considered as two. This will be rendered evident by the following table:—

Thus high-pressure steam of

0 lbs. on the square inch is called	0 atmos.	or	1 atmos.
15	1		2
30	2		3
45	3		4
60	4		5
75	5		6
90	6		7
105	7		8 &c.

Owing to this ambiguity in these technical measures, it is always necessary to observe, and to specify, whether the pressure intended be pressure total or excess above the atmosphere of air. If, for example, four atmospheres be specified, it must be considered whether four above the pressure of the atmosphere be meant, as in the first column of the table, or four including the atmospheric air pressure, in which case the number on the second column is meant; for in the former case steam of 60 lbs. in the square inch is meant, and in the latter steam of only 45 lbs. above the atmosphere. We have already seen how the force of steam, confined in a close boiler, and heated until it acquires high pressure, acts upon every point of the surface in which it is enclosed, tending to press it asunder; and how, by sufficiently confining and heating it, weights of five, fifteen, or fifty pounds, resting on only a single square inch of surface, may be supported and upraised. To apply this force to the raising of great weights, is sometimes the object of the high-pressure steam-engine; and it has been calculated that six pounds of coal, applied in heating

six gallons of water into steam, has sufficient force to perform the most arduous labour of a man for a whole day.

One of the simplest and earliest applications of the force of high-pressure steam to raising weights is given by Jacob Leupold, in his *Theatrum Machinarum Hydraulicarum*, Leipzig, 1725. It is evidently borrowed from Dr. Papin. Another is a true water-pumping high-pressure steam-engine, and might be efficiently used without any alteration at the present day, only the modern machines do the work with less fuel. Two pumps for raising water are directly worked by steam, by connecting the handles of these pumps with the pistons of two high-pressure cylinders, in such a manner, that when the pistons are raised by the steam the water is forced up in the pump-pipe. The first method of regulating the admission of steam, and cutting it off when required, was by means of a *four-way cock*. The next was the invention of a valve-box, or valve-chest, to contain all the four passages—viz., steam, eduction, upper and lower. Into this box is introduced a small valve or cover, which is of such a size as at one time to leave open only one of the three openings; so that, by covering two of the openings, the steam can only find its way into the lower part of the engine, while the steam already in the upper part of the cylinder can find its way into the eduction-pipe. The next position is where all the three passages are closed, preparatory to reversing the direction of the steam, as in the third position when it slides from the upper part so as to allow the steam to enter above the piston and press it down, while the steam formerly below the piston escapes into the air through the lower passage by the eduction pipe. This valve, named from its figure the D-valve, is also worked by the machine itself, either by some of its moving parts striking plugs on a rod which is fixed to the valve, or by some of the other apparatus.

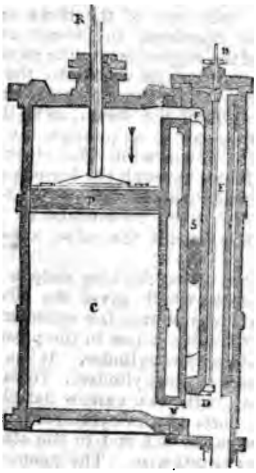
Another form is that called the long slide or long D-valve, the invention of Mr. Murdock, which gives the advantage of shutting off the steam, close to its ingress into the cylinder; and so saving what in the common short D-slide is lost in the passages. The valve-chest extends along the side of the cylinder. It is a sort of pipe extending along the whole length of the cylinder. Towards the ends, this pipe is almost semicircular, with two narrow flat plates capable of covering the openings or ports of the cylinder. This pipe is left open, and perfectly clear from the one end to the other, so that the steam may traverse it freely lengthwise. The steam-pipe enters the valve-chest from below, and the eduction-pipe in the middle. In this valve-chest are placed packing-boxes, as they are called, immediately opposite the ports of the cylinder. They contain soft elastic hemp, soaked in oily matter, the object of which is to press against the truly cylindrical and polished outside of the slide-valve when in its place, and make steam-tight partitions in the valve-chest, to prevent communication between the middle and the two ends. In this species of slide, there is scarcely any loss of steam in the passages, and it is cut off close to the cylinder.

Instead of the long D-slide, which is very heavy on a large scale, *two short slides, similar* to its two ends, and connected together by

bars, have been used. In this case, however, there are two eduction-pipes instead of one as formerly, and the steam-pipe enters between the valves. A cylindrical slide-valve is used in a considerable number of engines, and works well. The valve-chest is an upright cylindrical pipe, the inside of which is bored truly cylindrical, and is exactly fitted by two metallic cylindrical plugs, which are ground so smooth in their places as to be steam-tight. These two plugs being raised and depressed by the valve-rod which connects them, will effect the same purpose as the former valve.

The arrangement of the steam-valves ultimately adopted by Mr. Watt, in his double-action engine is shown in Fig. 21, in which we have preserved the same letters as in Fig. 16 for the parts which answer the same end as in that apparatus, and have omitted all the lower portion, which is not in any way changed.

Fig, 21.



WATT'S DOUBLE ENGINE APPARATUS.

The vertical rod OD, instead of having three discs answering to the same number of openings, is simply furnished with one single piece (distinguished by cross-shading), which is the slide-valve. In the position represented in the figure, the slide-valve admits the steam conveyed by the transverse tube s, above the piston, while a communication is established between the lower portion c of the cylinder and the condenser. The piston will then descend as in the single acting engine. When it has arrived at the bottom of the cylinder, the rod OD descends, bringing down the slide-valve with it; and the upper part of the slide-valve descending completely below the opening F,

the lower portion of it also descends below the opening v. Then it is the upper portion of the cylinder which communicates with the condenser, while the steam issuing from the pipe s presses upon the lower surface of the piston.

In immediate connection with the valves and passages of a steam-engine, which admit the steam on alternate sides of the piston to do its work, and afterwards discharge it, we may consider the means by which the engine is rendered automatic, or capable of performing its labour, in the most perfect manner, without the continual assistance of a man to open and shut its valves. There are two ways in which valves are worked by the steam-engine itself. The first of these is by the agency of some part of the engine that happens to move up and down, or performs a reciprocating motion, and the other is by the agency of some part which revolves.

The method of moving the valves by a plug-frame, rising and falling with the strokes of the piston, was first introduced by Beighton (with very different valves) about the year 1718. It has been principally adopted for pumping engines that have no revolving motion. It is, however, used with advantage in marine engines. It is noisy, as the sudden strokes of the plugs produce an instant jerk; but it is effective, in so far as it once opens the ports to their fullest extent, and so allows full effect to the entering steam, and full clearance to that which is escaping.

A new method of working the valves has been invented by Mr. Melling, superintendent of locomotives on the Liverpool and Manchester railway. It derives the motion of the valves from the connecting rod, one end of which moves round in the circle of the crank, while any point between the ends performs a sort of elliptic motion. Thus a round pin is made to project from near the middle of the connecting rod, and the curve described by this pin manifestly resembles, although it is by no means a correct ellipse. It is an oval having its lower end more acute than the upper, and deviating the more from a true ellipse as the connecting rod is shorter. Since the pin does not describe a circle, it is made to act in a slit in an arm which proceeds from a fixed axis in the centre of the oval. This arm the pin carries round, together with a small crank on the same axis; and the valve rod is moved by this crank just as by the eccentric.

One of the most common of the many applications of the steam-engine is to turn round an axle and wheel; and in the second system of valve apparatus, by which the steam-engine is rendered automatic, the steam-valves are worked by the revolving of one of the shafts or wheels. Of the various methods in which this has been done, the following are examples. On the axis of the crank which is turned round by the connecting rod during each alternate ascent and descent of the piston, is placed a cam or projection. A square frame encloses this cam. As the axis turns round, the cam comes into such positions as to bear upon the sides of the frame successively, and so pushes the frame towards the right and left alternately. There is a bell crank to which a horizontal rod attached to the frame moves on its centre, and so shifts the valve-rod up and down alternately together with the valves. Another form in which this motion has been

given, is by connecting the large axle of the crank with a smaller axle, by toothed wheels. The principal or crank axis carries the driver. There is a projecting pin out of the centre, on the driven, to which a crank is connected by a rod so as to raise and depress the valve-rod. It is manifest that, during the revolution of the wheels, the pin will be carried round a circle, and communicate alternate motion to the rod, equal in extent to the diameter of that circle. This circle must, therefore, be chosen of a diameter equal to the required motion or throw of the steam-valves attached to the cylinder. This motion has been modified into a very excellent and durable arrangement by Messrs. Carmichael, of Dundee. Another mode of moving the valves is by a projection in the great axis of the engine itself. A rigid circular hoop encloses the axle, the axle and its projection being equal to the diameter of the hoop, the projection or cam, in passing round, pushes the hoop in alternate directions. But that modification of this principle, which is in by far the most general use, is in the form called "the eccentric," which is a circular disc, or ring of metal, placed upon the shaft or axis turned by the crank. On the centre of the shaft or axis, to which revolution is given by the crank of the steam-engine, a circular disc is placed, but eccentric to it, so that its centre moves round the axis. The distance of the centre of the disc from the centre of the axis, is called the eccentricity, and it is equal to half the throw or range of the motion of the valves to be moved by the eccentric. The rod, called the eccentric rod, is attached to a hoop or circle that exactly fits the eccentric disc.

One of the most important appendages of the steam-engine is the crank, by means of which the force of steam, although at first producing motion only upwards and downwards in the straight line of the axis of the cylinder, is nevertheless rendered capable of exerting that force equally well in a circular direction. When the steam-engine is only employed for some such purpose as pumping up water, no crank is necessary, but in some of the most usual and valuable applications of the steam-engine such as those where it turns wheels of mills, of cotton-machinery, of steam-vessels, or locomotive engines, the crank, by which this is accomplished in an admirable and simple manner, has superseded every other plan of transmission. A crank is an elementary machine which has been used from the earliest times for converting a revolving into a rectilineal motion, or the reverse. It is figured in description of the old machines of the Egyptians, Chinese, Greeks, and Romans, and in water machinery it has been in common use from the time of Ctesebius. A crank is merely a handle to a wheel, by which it may be turned round. By a rigid metallic connecting-rod, instead of a man's arm, the force of steam is applied, through a cylinder, piston, and piston-rod, to the crank, by means of the connecting-rod; and the steam turns round the wheel by means of the crank, axle, and pin.

In the action of the crank, it is to be observed that the force exerted by the steam is neither constant in direction nor in action. If the steam be admitted first below the piston, it forces it to the top of the cylinder; it is then cut off preparatory to its being admitted above the piston; and in the interval it has no motive action. When ad

mitted above the piston, it forces it to the bottom of the cylinder; and again there is a cessation in its action during the change in the position of the valve. Now it is evident that this recurring cessation of action between the alternating impulses would interrupt the continuous revolution in the wheel, but for the power of the wheel itself to continue the motion, by what is termed the momentum of its mass. When the steam, during a stroke of the machine, is acting most powerfully on the piston, part of its power is spent in accelerating the wheel; and when, at the end of the stroke, it ceases for a time to act, the wheel gives out the power which it had gained, and continues its motion until the next stroke gives it a fresh accession of power. A wheel of this kind, when attached to an axle for equalising motion, is termed a fly-wheel; and to obtain the full benefit of its equalising power, it is made of large diameter, that its rim may move rapidly, and it is made of great weight, being formed either of lead or iron, that it may acquire momentum to render the motion as uniform as possible. Still the equalisation of the motion produced by the fly-wheel is partial, not perfect. Matter only takes up or gives out force when it changes from one velocity to another. If, therefore, the fly-wheel in the motion take up into itself the accession of force of the steam at one part of the stroke, it does so by slightly accelerating its motion; and if it give out force during the cessation of the stroke, it is by slightly reducing its own velocity in so doing. The approximation to perfect uniformity of the steam-engine, will be proportioned to the mass of matter in the rim of the wheel and to the square of the wheel's velocity. Although, therefore, the fly-wheel improves the action of the crank, so as to adapt it to all ordinary purposes, still the effect is not so equable as the power of a water-wheel, where extreme delicacy is required. In all ordinary cases, it is sufficiently uniform.

From the circumstance already noticed, that at one point the steam possesses no power of turning the crank, it has been imagined that some considerable loss of the power of the steam takes place during its transmission through the crank. When the connecting-rod and crank are in the same straight line, technically called the position "on the centre," or passing the line of centres, the action of the steam neither tends to turn the crank in one direction nor the other. When the crank is acted upon at right angles by the connecting-rod, it is plain that the whole force transferred through the rod is acting to turn the crank; while in the intermediate positions there are two efforts, one acting on the centre of the crank, and another to turn it round; so that, while the pressure of the steam acting through the connecting-rod upon the extremity of the crank, is divided into two effects, one of these is prevented from expending the moving force of the engine by the fixedness of the crank centre, and the whole motive power is given out only at the circumference of the crank circle, in turning it round, but in a proportion of pressure that is continually varying from 0 to a maximum, and from a maximum to 0, through every successive quadrant of the circle. The amount of the variation is shown in the following table, which consists of the sines of a

series of angles which increase continually by 18 deg., the radius being 100:—

Points in the circle of revolution.			Pressure in direction of revolution.
0	and at	20	0.90
1	„	19	30.90
3	„	18	58.78
3	„	17	80 90
4	„	16	95.11
5	„	15	100.00
6	„	14	95.11
7	„	13	80.90
8	„	12	58.78
9	„	11	30.90
10	„	10	0.00
		Mean pressure	63.11

The mean pressure on the crank being in the table about 63 pounds, taken on an average of the whole circumference of the circle, the pressure varies from 36 pounds above the mean, to 63 pounds below it. The total pressure of the steam in the cylinder forces the connecting rod up and down through a space equal, each time, to the diameter of the circle, while the connecting-rod carries the crank through a space which is equal to the whole circumference; and as the circumference of a circle bears to twice its diameter an approximate ratio of 100 to 63, it follows, that the pressures on the crank and piston are inversely as the spaces through which they move; the motive power of steam in the cylinder being 100 lbs. moved through a space of 63, and the motive power given out in the crank, being a mean of about 63 lbs. moved through the circumference of a circle which is represented by 100, so that the motive power in the one case, is 100 lbs. + 63 = 63000 lbs.; and in the other case 63 lbs. + 100 = 6300 lbs. One method of equalising the rotative pressure on the crank has been proposed, which is very generally adopted, viz., to make two steam-engines act on the same axis by means of two cranks at right angles to each other, so that when the one ceases to exert force, the other may be at its point of greatest force. This is particularly the case in locomotive engines on railroads.

The connecting-rod is a rigid bar of metal which conveys the motion of the piston from the piston-rod to the crank either immediately or through the interposition of the lever or beam; and as the connecting-rod, in doing so, takes various directions different from those either of the piston-rod or of the crank, there is an obliquity of pressure produced at both extremities of the connecting-rod, which gives rise to a variation of force and direction, that must be practically provided for, and carefully appreciated in quantity, in so far as it may affect the ultimate operation of the machine. There are two ways in which the motion of the piston rod is most commonly transferred to the crank; either immediately through the connecting-rod, forming crank engines without beams, or as they are also called, *direct action engines*, which are daily coming into more general use;

or through the medium of the great lever, both ends of that lever describing circles around its middle fulcrum as a centre, and the head of the piston-rod being connected with the one end of the lever by means of an iron strap or connecting-link. In these, the connecting-rod or link is never, except at two points, in the same straight line with the piston-rod, so as to propagate its unmodified force to the crank; in the oblique positions it would produce a lateral motion in the end of the piston-rod which would not only be a waste of power in producing motion in a place where it is useless, but would have the effect of continually bending the piston rod in opposite sides, so as either to break it, or materially to impair its working. To prevent these oblique pressures from thus wasting the power of the steam, is the object of a series of contrivances called parallel motions, or parallel guides. The most notable of these we owe to Mr. Watt, already adverted to in the preceding chapter. This elegant and simple contrivance is not, however, absolutely perfect. At the best only a part of the line which it describes makes an approximation to a straight line of scarcely sufficient length, and beyond which the stroke of the piston cannot be increased without being seriously deranged. Nor can this be remedied, but by constructing the apparatus on a scale so large as to be highly objectionable. In such an arrangement the head of the piston-rod is not kept perfectly in a straight line, but is, on the contrary, compelled to deviate from it so as to describe a looped curve. The nature of this deviation will become very evident if we suppose the parallel motion to be altogether detached from the piston-rod, and the motion of the parallel-bar and link carried to its extreme. It is most important to diminish this deviation which increases more rapidly than the square of the length of the stroke. This is most commonly done, as in all Watt's engines, by a jointed parallelogram. Another form of Mr. Watt's invention consists in placing two bars in the same direction, with such a difference in their length as may afford the means of compensation.

All these motions being imperfect, various plans have been adopted for remedying the evil. In American steam-engines, Watt's parallel motion has been to a great extent abandoned, because in them long strokes and long cranks are preferred; and because in such cases the deviations of the head of the piston-rod, from a straight line, would, with Watt's methods, become excessive. Watt and his followers were perfectly aware of this, and hence were led to construct beams, with connecting-rods, and parallel motions, of very great length, so as to diminish the evil as far as possible. This has, of course, the effect of rendering the whole engine both bulky and expensive, and is, therefore, in many cases inexpedient. The American engineers, therefore, use the sliding parallel motion; that is, they have substituted for the radius bars of the parallel motion of Mr. Watt, a sliding bar or groove in which the top of the piston-rod is guided. The head of the piston-rod is enclosed between two flat surfaces, or between two parallel iron bars, which are kept in the vertical position by means of stiff-framing: on these it slides; and to diminish the friction *wheels may be added*. Another species of parallel motion adopted *in America, and used* in this country, is the engine with vibrating

pillar. The pillar, which supports the beam or lever, instead of being fixed in an upright position, has a joint at the bottom, on which it and the beam and the crank-rod perform a joggling motion backwards and forwards during each stroke. The oscillation of the moving mass of the engine in alternate directions, with a sudden jolt at the end of the stroke, renders this a bad engine when made on a large scale.

The elegant cycloidal parallel motion was invented by Mr. James White, and published in his "New Century of Inventions" in 1801. It depends on this principle that an encycloidal curve, described by one circle rolling within another, approaches a straight line as the inner circle becomes more nearly equal in diameter to the radius of the outer one. To apply this principle, a large wheel, with teeth on its inner circumference, is fixed on a frame concentric with the axis and circle of the crank. A wheel with external teeth is fixed freely on the crank-pin, and the point of attachment to the piston-rod is fixed on its circumference. By this arrangement, the small wheel is compelled, by the pressure of the piston-rod upward, to roll round the great circle, ascending on one side and descending on the other, so that the distance of the end of the piston-rod from the point of contact of the circles, is always equal to the distance of the circle from the diameter, and thus the straight line is always preserved.

The governor is an appendage to a steam-engine, of much value in regulating all its applications to the production of uniform revolving motion. It is merely a modification of an apparatus similar to the pendulum, and by which Huyghens once attempted to regulate a time-keeper, instead of using the common pendulum. The height for any required number of revolutions is equal to the length of a simple pendulum, which will give double the number of vibrations in the same time. If the mass of the ball and rod were supposed to be collected into a point, the length would be had by the following easy rule:—Divide 35226 by the square of the number of revolutions per minute, and the result is the height. Thus to find it for 30 revolutions per minute:—

we have $30 \times 30 = 900)35226$

required height $= 39{\cdot}14$ inches.

A substitute for the governor, depending on the resistance of the air, and having nothing to do with the conical pendulum, has been invented and patented by Mr. Hick, of Bolton. A very oblique screw is formed on the usual upright spindle. To this is fitted a heavy screw nut, or socket, furnished with two horizontal arms and vertical vanes, in such a manner that when the spindle revolves rapidly, the resistance of the air on the vanes retards the socket, so that, owing to its not revolving so fast as the spindle, it rises by means of the screw, and at the same time lifts the usual horizontal lever. When again the motion of the whole becomes more languid, the weight of the socket causes it to descend on the spindle.

The parts of the condensing steam-engine hitherto examined are in all respects identical with those of the high-pressure steam-engine. The characteristic difference consists in the manner in which the

steam is disposed of after having done its work, and in the apparatus required for the purpose. In the high-pressure engine, the steam is discharged from the cylinder simply by allowing the entering stream to press the piston upon the outgoing steam, and force it through the eduction-pipe into the open air. Now, it requires considerable force to effect this: we know that the atmosphere must be pushed away before the steam with a force of about fifteen pounds on each square inch of the surface of the pipe; and therefore this much of the force of the steam, which is a balance for the air—that is, an atmosphere of steam—is consumed or thrown away in this employment. In the condensing steam-engine, this atmosphere is saved. The steam being liquefied almost instantaneously, a vacuum is formed on one side of the piston, and that part of the power which formerly was spent in the useless labour of forcing the steam into air, is now employed in useful labour.

The most improved and most generally used form of the steam-engine is the *double-acting engine* of Watt. The moving power in this machine is rendered operative by means of a piston placed in a cylinder, closed at top and bottom, in which it moves steam-tight. The piston is connected with the end of the working-beam by a rod moving in an air-tight collar or stuffing-box in one end of the cylinder. The beam is supported on its axis, and has a connecting rod to convey motion to the crank and shaft. When the engine is to be put in motion, the atmospheric air and other gases are expelled from the cylinder and the tubes which communicate between it and the boiler, by steam, which is allowed to pass freely through them, and escape through a valve or cock provided for the purpose, until all the air be blown out of the engine. The cock is then closed, and pure steam fills every part of the engine. A vessel or chamber, called a *condenser*, which is maintained at a low temperature by being immersed in cold water, is made to communicate with both ends of the cylinder by means of proper tubes and valves worked by the engine. When the piston is required to descend, the communication between this chamber and the bottom of the cylinder is opened, while a communication is at the same time opened between the boiler and the top of the cylinder. The steam which fills the cylinder below the piston rushes towards the condenser by its elastic force, and is there immediately converted into water by the cold medium with which it is surrounded, a jet of water being allowed to play into the condenser. The space of the cylinder below the piston is thus rendered a vacuum; instantly the steam rushing from the boiler on the top of the piston, forces it downwards, till it reaches the bottom of the cylinder. The communication between the boiler and the top of the cylinder is now closed, and a communication opened between the boiler and the bottom of the cylinder; and, at the same time, the communication between the condenser and the bottom of the cylinder is closed, and a communication is opened between the condenser and the top of the cylinder. Under these circumstances, the steam above the piston rushes, by its elastic force, towards the condenser, as before, where it is immediately condensed, and the space of the cylinder above the piston is made a vacuum. The steam from the boiler then instantly rushes into the

cylinder below the piston, and forces it upwards to the top of the cylinder. In this manner the alternate motion of the piston, upwards and downwards, is continued; this motion is communicated to the beam by the piston-rod, and from the beam to the crank by the connecting-rod. All the communications are effected by valves which are opened and closed by apparatus attached either to the working-beam or the crank-shaft. The air pump, which clears the condenser of air and water, the cold-water pump, which supplies the cistern, and the hot-water pump, which supplies the boiler, are all worked by connecting-rods attached to the working-beam.

The *single-acting engine*, which is also the invention of Watt, differs from the preceding in this principal respect, that the force of steam is employed only to produce the downward motion of the piston, the reverse motion being effected by a counter-weight attached to the other end of the working-beam. When the piston, by the operation of the moving power, reaches the bottom of the cylinder, a communication is opened between the boiler and the bottom of the cylinder, and steam is admitted below the piston as well as above: the communication between the cylinder and condenser is opened, the steam is condensed, the piston descends, and the operation is continued as above described. The other parts of this engine are similar to those of the double-acting engine.

The principal difference between an atmospheric engine *with a condenser*, and a single-acting steam-engine, consists in the steam being admitted both into and out of the cylinder by communications at the bottom, and the descent of the piston is effected by the pressure of the atmosphere on its upper surface, the cylinder being open at the top. In the atmospheric engine, as it existed before Watt's invention of the separate condenser, the jet of cold water was thrown into the cylinder itself at every stroke of the piston; consequently, the cylinder was alternately heated and cooled at each stroke, at a great expense of fuel and cold water, and a corresponding loss of steam.

Having thus prepared the way for the complete comprehension of the different parts of Watt's *double-acting condensing steam-engine*, of which the combination appears complex at first sight, we now exhibit the representation of a model of this engine in Fig 22, accompanied with a short description.

All the parts are shown clearly in this figure, and the particular shape of the frame and beam are, as it were, stereotyped from the manufactory at Soho. The cylinders are supposed to be made of glass, to show the operation of the fluids.

A is the cylinder in which the piston moves when acted on by the steam alternately above it and below it.

B. The isolated condenser and cold water jet.

C. The air-pump, for extracting air and condensed steam from the condenser.

D. The feed-pump, for raising the water employed in the condensation of the steam.

E. The force-pump, which conveys into the boiler the water heated by condensation.

F. The vessel containing this water.

attended with greater success. It appears that they were the invention of the French Engineer, Cugnot. But his carriage, at the time of the trials to which it was submitted, threw down part of a wall. Evidently, he had not been able to discover the means of giving proper direction about this engine. It is still exhibited in the collections of the "Conservatoire des Arts et Metiers" at Paris.

Following up the idea, which had long been known, of a high-pressure engine without a condenser, Messrs. Trevethick and Vivian constructed one in 1805, to be applied in the first attempts at locomotion upon a railway. Improvements were slowly introduced, and it was not till about 1814 that Mr. Stephenson established carriages of this kind on proper principles. In 1829 a great revolution took place in the art of constructing locomotive carriages. At this period, when the brilliant experiments in this department were made upon the railway from Liverpool to Manchester, there were exhibited for the first time locomotive engines, travelling easily from twenty-five to thirty miles an hour, and yet completely under the guidance of the driver. In less than six years after this, a locomotive made by Messrs. Sharp and Roberts travelled on the same railway with a speed of sixy miles an hour!

In all our locomotive machines on railways, the *high-pressure non-condensing steam-engine* suggested by Watt, in his first specification of 1769, is constantly employed. It is placed to work horizontally, instead of vertically, as in ordinary engines, in order to save room in the height of the machine. The following illustrations are given as representations of the mechanism of locomotive engines, according to the mode of construction which has been employed of late years. The more recent engines are constructed with six wheels, instead of four as in the illustrations here exhibited; but the engravings will serve the purpose of conveying a clear idea of locomotive machines as they are used at the present day. Fig. 24, is a side elevation of the locomotive engine, as placed upon the rails. The arrow in the engraving indicates the direction of its motion. Fig. 25 represents a longitudinal and medial section, in which several accessory parts are omitted, to favour the clearer comprehension of the rest, especially the action of the cylinder and piston, and of the crank and wheel; *e* is the furnace, surrounded by a rectangular box placed in the hinder part of the machine. It is represented in tranverse sections in Fig. 26, and is called the *fire-box*. This box is surrounded by a space *qq*, seen in both figures, which is in free communication with the boiler, and is filled with water. The fire-box is rivetted by strong bars to the outside box which contains it, and is surrounded with water in every part, except at the opening *l* in fig. 25, which forms the door of the furnace; and at the bottom of the box, which is occupied by a grating, the bars *nn* of which are seen in longitudinal section in Fig. 25, and in tranverse section in Fig. 26. The bottom of the furnace-door is slightly elevated above the upper surface of the *frame* of the engine YYY (Fig. 24), and above the *foot-board* situated in BB, at the hinder part of this frame, in front of the said door. Upon this foot-board, guarded at the side by hand-rails, the engine driver stands. The fireman is placed very near the foot-

board, in front of the *tender*, which is a kind of waggon which carries the supply of fuel and water requisite for the journey. The furnace is charged with coke by the door *l*. From the fire-box issue a considerable number of horizontal tubes *e′ e″* (Fig. 25 and 26), through which the gases, flame, and heated air produced by the combustion of the fuel, are made to pass into the smoke-box *h*, where they expand, and ultimately issue from the chimney c, which in the illustration is represented as broken off, to save room in the engraving. By this means, a continued current of combustion is directed upwards through the grating of the furnace, and through the tubes to the top of the chimney. Throughout the whole extent of this passage, the high temperature of the products of the combustion is applied to the heating of the water, in which the tubes are entirely immersed, and in partially vaporising the water. In the boilers of fixed engines, two large tubes, which are filled with water, are surrounded by the fire; in locomotive boilers, on the contrary, it is the water which surrounds the tubes through which the fire passes. To the tubular form of the boiler, and to the discharge of the waste steam up the chimney, must be attributed the chief cause of the power which locomotive engines have acquired within the last twenty years. The number of tubes employed at the present day in a boiler, is about a hundred and fifty.

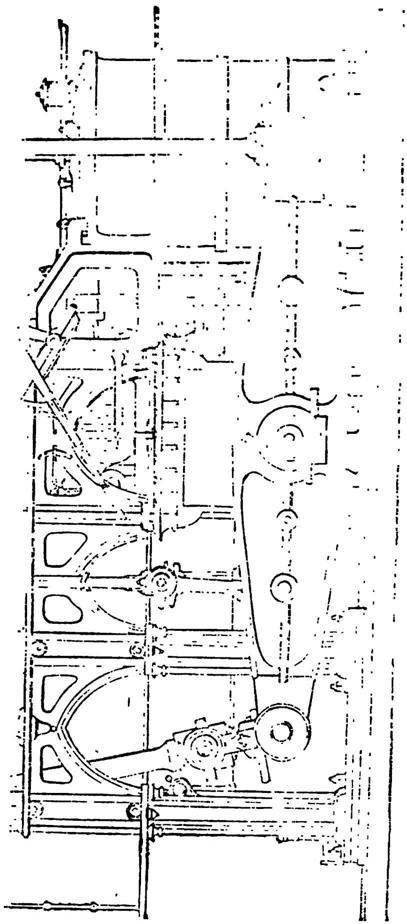
The generation and distribution of the steam takes place in the following manner:—It occupies the whole space of the boiler between the level of the water *c d*, Fig. 26, and the cylindrical segment above it. It accumulates in this space, and is allowed to attain a pressure of three, four, or five atmospheres beyond the ordinary atmospheric pressure. Beneath a dome placed at the hinder part of the engine, is a vertical tube v, communicating with another tube v′ v″, placed horizontally and entirely surrounded by the steam. The steam following the course indicated by the arrows, is introduced into the horizontal tube with a velocity regulated by the extent to which the tube is opened or closed by a diaphragm, situated at v′, called the *regulator*, and worked by the handle T. At the end v″ of the horizontal tube, are two curved tubes *v* (of which only one is seen in the engraving). Passing through these tubes, the steam fills the whole space or steam-box x. It then passes through the aperture 1, which opens into the cylinder behind the piston P, and pushes it in the direction of the arrow. The piston P thus arrives at the end of the stroke, driving before it the steam in the front part of the cylinder, which makes its escape through the openings 2, *i*, and issues thence into the pipe v‴. The steam thus driven out carries off with it a considerable volume of air, which, creating a draught upwards, draws a fresh volume through the tubes of the boiler and the furnace. The effect is analogous to what would be produced by a pair of bellows, which should continually act upon a fire by drawing the air into the bellows instead of driving it out into the fire, like the ordinary bellows; and this effect produces a power in the engine that no other means could accomplish. The idea of applying this principle to increase the draught of a chimney, originated with Philibert Delorme, *in 1567, as stated in* our second chapter.

In the portion marked x, is the slide-valve, v
has arrived near the end of the stroke, is pu
rod *o*, so as to intercept the passage of the st
and to leave that marked 2, entirely open. The
will then enter in front of the piston, and pre
surface, will push it backwards, or contrary
arrow; while the steam, which has accompli
again driven out into the chimney by the openi
This alternate motion of the piston is trans
connecting-rod having two joints to the cranke
which is seen at Y and Z (Fig. 25); and as th
fixed upon the axle, they turn round so as to pro
movement of the locomotive. The parts are
one stroke of the piston from end to end of the
turns one quarter of its circumference; so tha
revolution, it is necessary that the piston should
cylinder in each direction; that is, make four alter
there are two cylinders and two pistons, placed
tudinal axis of the engine, there are also two cr
connecting rods; but the second crank is plac
right angles to that of the first; so that when one
the *dead-point* at the end of the stroke, the other
maximum force.

The head of each piston-rod works between
(Fig. 24), which ensure its motion in the directio
cylinder, and at the same time support it.

The motion of the valve-rod is effected in the f
This rod, acting upon the slide valve x, opens
steam alternately before and behind the piston.
o (Fig. 25), and is attached to the end of a lev
upon a fixed point, shown at K (Fig. 24). The f
ceals the upper end of this lever, and the rod *o*.
of the lever, is fixed a horizontal rod, of which the
and which passes backwards beneath the engine.
if a backward and forward motion be given to this
the lever will follow it in all its motions. This le
the point K, its other end will assume opposite p
when L moves forward, the upper end moves back
goes backward, the upper end comes forward. Th
fastened to this end, participates in all these motio
slide-valve x (Fig. 25) alternately backwards and
cessively closes and opens the passages 1, 2, and
the great rod I L, itself, is effected by means of a
the simplest pieces of mechanism which can be empl
circular motion of a wheel upon an axle into an al
motion. Such are the simple means employed for t
engine. When the fire has been lighted about an
two hours, and the steam has acquired a proper d
regulator is opened by means of the handle T. T
the piston; the wheels turn round very slowly at
quicken their speed. The engine is kept going

Fig. [illegible]7.



DERN STEAM-BOAT [illegible]

city by opening or closing the regulator to a greater or less extent, stirring up the fire, and using other necessary precautions.

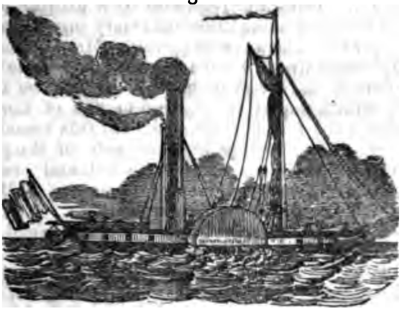
In the first year of the present century, Mr. William Symington, engineer, at the instance of Lord Dundas, made experiments on the application of steam to the propulsion of vessels on the Forth and Clyde Canal, which ended in the production of the *first practical steam-boat*, named the *Charlotte Dundas*. In this vessel there was an engine, with the steam acting on each side of the piston (Watt's patent invention), working a connecting-rod and crank (Pickard's patent invention), which was united to the axis of Miller's improved paddle-wheel (Symington's patent invention, 1801). Thus had Symington the undoubted merit of having combined together, for the first time, those improvements which constitute the *present system of steam-navigation*. In 1807, Mr. Robert Fulton, an American engineer, after having taken sketches and drawings of Mr. Symington's boat in Scotland, in 1801—as attested by the engineer left in charge of it—went to America and built the steam-boat *Clermont*, which first plied between New York and Albany, and was reckoned the first steam-boat that was put into actual practice in America or elsewhere; but it was only a copy of the *Charlotte Dundas*.

The first steam-boat that was put in actual operation was the *Comet*, built by Mr. Henry Bell, of Helensburgh, in Dumbartonshire, in the year 1812. It began to ply for passengers upon the river Clyde, between Glasgow and Greenock, on the 5th of August of that year. It was a small vessel of thirty tons, and had an engine estimated at three-horse power. Mr. Bell had obtained a knowledge of the plans of Mr. Symington, and had communicated with Mr. Fulton on the subject. Thus at Helensburgh, in the firth of Clyde, nearly opposite to Greenock—the birth-place of the illustrious Watt—and at a distance only of six miles, originated the first practical application of the modern steam-engine to the purpose of navigation in Europe, and the invention, also, of his own countryman. Very soon after this period, steam-navigation by paddle-wheels became general in Great Britain, and it thence extended over the Continent.

The steam-engines most generally employed for the propulsion of steam-boats are the double-acting condensing-engines of Watt. The engine-beam of these engines is inverted so as to be placed near the bottom of the frame, as it would be both inconvenient and dangerous in a steam-vessel to place it above. Fig. 27 represents the elevation of an engine of this construction, built for a transatlantic packet of 450 horse-power.

The following illustration (Fig. 28.) represents a steamer in full sail. On the sides of the vessel are seen the paddle-boxes, covering the paddle-wheels, to which the revolving shaft imparts the rotary motion. It is well known that for some years steamers have been constructed in which the paddle-wheels are superseded by a propeller, of spiral form, immersed in the water at the stern of the vessel. Hitherto the transatlantic vessels established on the paddle-wheel system, appear to make better passages than any which have been yet constructed on the new system.

Fig. 28.



STEAMER IN FULL SAIL.

In the Great Exhibition, a vast variety of steam-engines, both for the purposes of manufactures and locomotion, were exhibited; these belonged principally to the high-pressure class; and motion was communicated to them by steam conveyed in pipes clothed with hair-felt, under the flooring. These pipes derived their supply from five boilers, arranged with boiler-house near the north-west corner of the building. The system of clothing the pipes with thick hair-felt, and putting over that a casing of painted canvas, rendered it possible to carry high-pressure steam to a distance before thought to be impracticable. The pipes were supplied at intervals with globular water-traps, in which the water resulting from the condensation of the steam was collected, and from which it could be readily removed. The system of the non-conduction of heat was so complete, that no perceptible increase of temperature was experienced, even through the open flooring. The beam-engines of a former period, were very generally replaced, in high-pressure engines, by those forms of arrangement in which a direct communication of power is made from the piston to the crank itself. To the latter class belong the steam-engines with vibrating or oscillating cylinders; to the former, those in which the cylinder is fixed, and in which the rectilinear motion of the piston-rod is converted into the curvilinear one of the crank, with shafting attached to it through the medium of vibrating mechanism. several varieties of both of these kinds of steam-engine, were exhibited in action, driving cotton-spinning, weaving, and various other machines. Rotary steam-engines of different kinds were also exhibited: in most of these, the curvilinear motion necessary for driving machinery, was obtained without the intervention of the crank, and power was led off by bands from the shafting, directly operated upon by the engine. Some of these machines present the most singular and anomalous forms. There were, also, examples of the conversion of rectilinear into curvilinear motion. The Marine-engines, formed an extremely interesting part of the Exhibition. The ponderous engines, of the collective power of 700 horses, for driving the screw-propeller

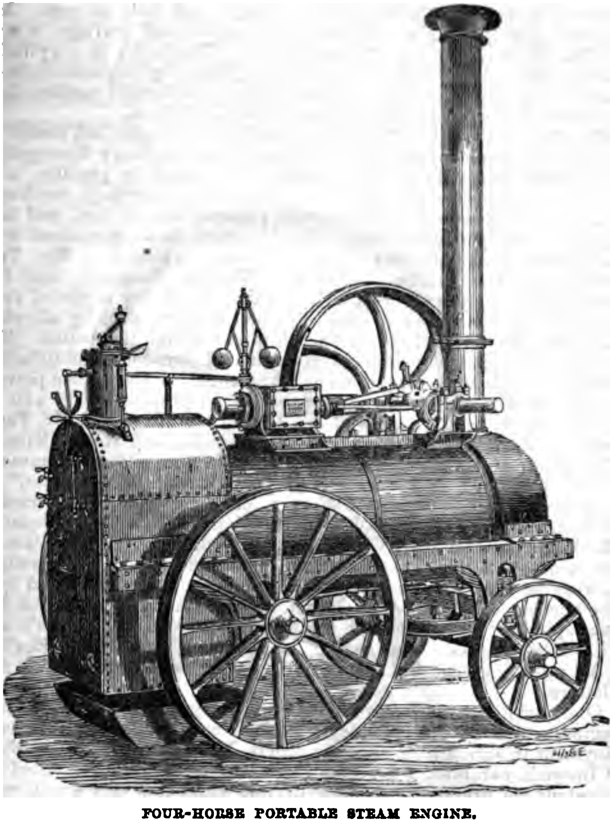
merely, and knocking the rails and sleepers to pieces, they were as anxious to get back their light engines as they had formerly been to discard them. This led to the introduction of the light "locomotive carriage" of Mr. Adams, and the light engine of Mr. England. The specimens which they exhibited, whilst possessing all the advantages which experience and skill have worked out in the heavy engines, are not more than one-third of the weight and half the cost. Mr. Adams' plan consists in combining the engine and carriage in one, so that there is no superfluous weight. The boiler is a cylinder full of tubes placed vertically; but this plan, in subsequent engines, has been given up in favour of the ordinary horizontal construction, as shown in the locomotive carriage in the Exhibition.

Mr. England, on the other hand, combines the engine and tender in one frame, thus adapting it to carriages of the ordinary description. Both these plans have been satisfactorily tested in practice, and bear out the views of the projectors, the engines carrying a moderate load at a high speed, with a small consumption of fuel, and less injury to the permanent way. In addition to these, specimens from numerous other eminent engineers were exhibited. Mr. Trevithick, of the London and North Western Company, sent the express engine, the "Cornwall," in which the boiler is placed very low, and the driving wheels are obtained of large size, by allowing the shaft on which they are fixed to pass through the boiler. Mr. Crampton, the patent narrow-gauge engine "Liverpool," said to be the most powerful engine in the world, being equal to 1140-horse power. The peculiarity of this engine consists in the position of the axle of the driving wheels, which is placed behind the fire-box. Mr. Fairbairn, of Manchester; Messrs. Wilson, of Leeds; and Messrs. Kitson, Thompson, and Hewitson, of the same town, exhibited specimens of the combined engine and tender variety, or "tank engines," as they are technically termed. There was also a very beautiful specimen of the first-class engine by Messrs. Hawthorn and Co., of Newcastle. The British visitor might consider, in dwelling on this collection of fire steeds, that in this respect at least his country had no competitor. A traveller tells, with pardonable exultation, how comforted and how much at home he felt at an Italian railway station by seeing on the name-plate of the engine the familiar words, "Sharp, Robert's and Co., Atlas Works, Manchester," and hearing a genuine English "All right!" given, before the train was allowed to move from the platform.

One of the greatest improvements in the application of the steam-engine, which was fully displayed in the Great Exhibition, is its employment in agriculture. Among others, Messrs. Ransome and May, of Ipswich, exhibited a portable steam-engine (Fig. 30), adapted for thrashing and other agricultural purposes, which is of very simple construction, and, having but few working parts, there is little liability to get out of order; the cylinder and the machinery are placed on the top of the boiler, and are therefore constantly under the eye of the engine-man, and very easy of access. The engine is fitted with a superior governor, and an effective regulator-valve for stopping and controlling the speed of the engine. There is a simple and efficien

feed-pump, which insures at all times a regular supply of water to the boiler. The crank-shaft and connecting-rod are of wrought-iron, and the slide-valve is of brass, and of the most improved construction.

Fig. 30.



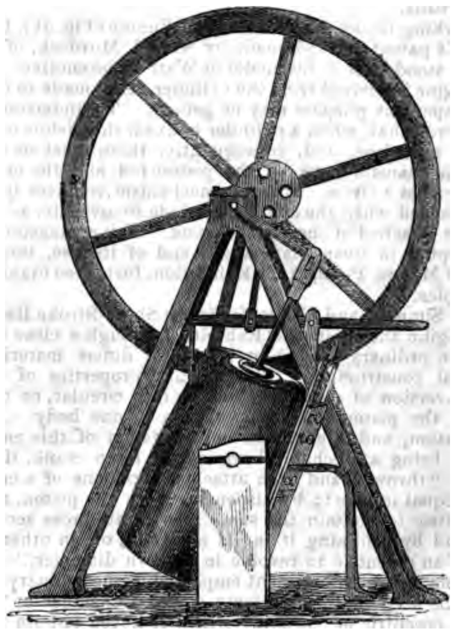
FOUR-HORSE PORTABLE STEAM ENGINE.

The steam and escape-pipes are of copper, and consequently not liable to injure the slide-valve and metallic packing of the piston, by any scales, caused by corrosion of the metal, coming off the pipes, and

being carried by the steam into the working parts of the engine, as is frequently the case in common engines fitted with wrought-iron gas-tubes (instead of copper) for steam-pipes. The boiler is of a superior description, and is made on the same principle as the best locomotive boilers, and will work with safety up to a pressure of 80 lbs. per square inch, if required.

This engine requires little fuel, and is free from danger by fire to the surrounding ricks and farm-buildings, the box being enclosed in a wrought-iron ash-pan, which contains water, and effectually extinguishes all hot cinders as they fall from the fire-grate. The engine is supported on a strong neat framing, which is carried on springs, interposed between it and the axles of the wheels. This arrangement

Fig 31.



MODEL OF WATT'S OSCILLATING MACHINE.

effectually preserves the machinery from the injurious shocks caused *by the roughness of* the roads over which they frequently travel.

These engines thrash, with ease, forty quarters of wheat of average yield per day, and are readily managed by an intelligent farm-servant, on whose care will depend, in a great measure, the quantity of fuel consumed.

There was also to be seen in the Great Exhibition, a model of what was called a "Model of Watt's Locomotive Engine."

It was interesting to examine this model, in connection with those complex, and, in some instances, stupendous machines, of which the Exhibition supplied so many examples. Franklin said of the first balloon:—"It is a babe; but it may become a giant." The balloon, however, is a "babe" still, while the locomotive presents to it a most striking contrast. If, in this model, we had "the babe," "the giant" was at hand inviting our contemplation. But it appears that the idea of a *rail* never entered the mind of Watt; all that he seems to have considered was, the movement of a carriage by steam on ordinary roads.

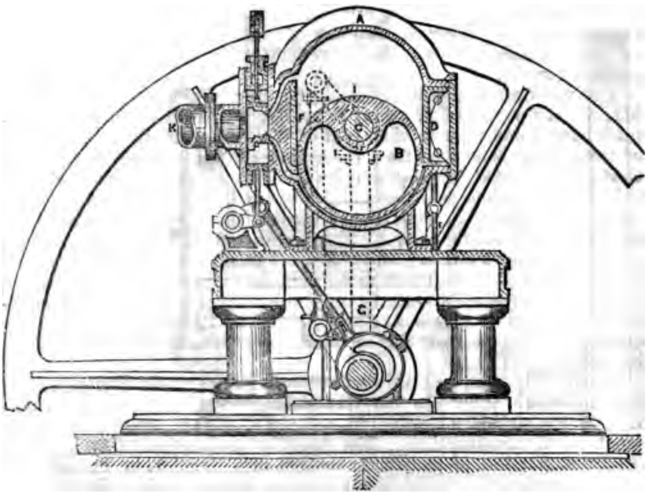
The working-model of an Oscillating Engine (Fig. 31), to illustrate Mr. Watt's patent of 1785, made by Mr. W. Murdock, of Soho, Birmingham, stood close to his model of Watt's Locomotive. The name of this engine is derived from the cylinder being made to oscillate, so that an important purpose may be gained. To understand this, let it be observed that, when a cylinder is fixed, the piston-rod can only describe a right line, and, consequently, there must be some intermediate mechanism between the piston-rod and the crank, as the latter describes a circle. But this mechanism requires space, which is greatly saved when the cylinder is made to oscillate, as the piston-rod can be attached at once to the crank. This arrangement is peculiarly adapted to steam navigation, and of its use, the oscillating engines of Messrs. Penn, in the Exhibition, furnished highly-interesting examples.

Messrs. Simpson and Shipton's Patent Short-Stroke Reciprocating Steam-Engine shown in the Exhibition, though a close approximation to the ordinary engine in principle, differs materially in its mechanical construction. The peculiar properties of it are—the direct conversion of rectilinear motion into circular, or the amalgamation of the piston and crank motion in one body. Fig. 32 is a side elevation, and Fig. 33 an end elevation of this engine. The eccentric, being a mechanical equivalent for a crank, if they be of the same "throw," and each attached to pistons of a certain area, they are equal in effect; by dispensing with the piston, and making the eccentric to contain the same area in its cross section as the piston, and by confining it in its extremes, or, in other words, by causing "an eccentric to revolve in its own diameter," is the same in principle as the arrangement employed in the ordinary engine.

It will be seen that A represents a steam chamber or "cylinder," and B the eccentric or "piston," which is keyed fast on the shaft C. The back plate, D, is fitted into the recess, and is pressed against the piston, either by means of springs, or by the admission of steam behind it by the small steam pipe, and is introduced for the purpose of compensating for any wear that takes place in the pheriphery of the piston. It also performs another important office: in cases of priming,

it is forced back, and the water rushes from one side to the other of the piston until it escapes. The plate E is dovetailed in and fitted fast, so that all wearing parts can be renewed with the greatest facility, compared with boring of cylinders, &c., in the ordinary engine. The piston is made steam-tight at both ends, with rings of metal, K K, fitted into conical seatings, which are cut open on one side, leaving a lap joint. The shaft C is carried on the vibrating rods F F, and vibrates the distance of the eccentricity of the piston—slots of suitable form being provided in the side plates, L L, to allow the shaft to traverse clear. G G are cranks, and H H are connecting rods

Fig 32.



SIDE ELEVATION.

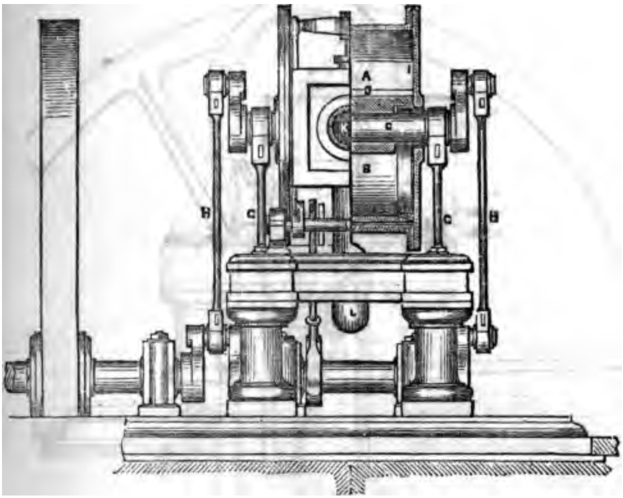
PATENT SHORT-STROKE ENGINE.

which convey the power from the piston to the lower cranks, through direct lines, and are always parallel. The steam is admitted into the cylinder precisely as in the ordinary engine, viz., top and bottom of the piston alternately; although the valve used in this instance is rather different, as it exhausts through the back, and is packed in a similar manner to the piston's ends, being worked by an eccentric, weight, shaft, levers, &c., as in an ordinary arrangement.

The advantages claimed for this invention are as follows:—The piston, receiving a reciprocative action from the steam, by reason of its mechanical arrangement, gives out a revolving motion, thus reducing the impetus at each return stroke; and from the fact of its

containing the properties of the piston and crank combined, not subject to the same straining of parts. Although the piston of the ordinary engine at all times receives the full effective pressure of the steam (when the valve is open), there are positions of the stroke when this is useless, as when the crank is "on the centre;" consequently the shock is sustained on the several cottars and parts, which is much felt in overloaded engines; but by the arrangements submitted, the crank shaft, which is the piston shaft, receives this shock, which is somewhat diminished on account of the piston itself gliding gradually out of equilibrium into full effect (the same as the common

Fig. 33.



END ELEVATION.

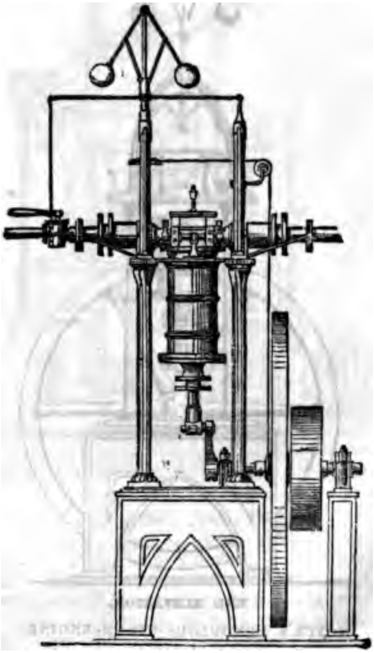
PATENT SHORT-STROKE ENGINE.

crank, though divested of the intermediate parts). An advantage is also obtained by working a short stroke with a large effective area of piston, and, consequently, a great speed, with slow velocity of the piston through space, is obtained, compared with the ordinary engine —thus the first motion can be attached direct to the main shaft, thereby not only dispensing with all intervention of wheel-work and its necessary appendages, but also producing a steadier motion, consequent upon the engine not having multiplying gear, which must only increase any inequalities in the stroke. This arrangement of engine requires but slight foundations, compared with others, from

the peculiar manner in which the power and resistance are pounded together, and, from the fact of the capability of these er to run at high speed, a large power can be concentrated into a space; hence if such results be obtained, and the multiplying g be dispensed with, and the number and weight of the parts r duced, there must of necessity be economy in first cost; and fro close approximation to the ordinary reciprocating engine, wit aforesaid advantages, the inventors ensure economy in fuel.

Mr. Joyce, of Greenwich, exhibited what is called a "high-sure pendulous engine." Fig. 34 and 35 represent a front an

Fig. 34.



SIDE ELEVATION.

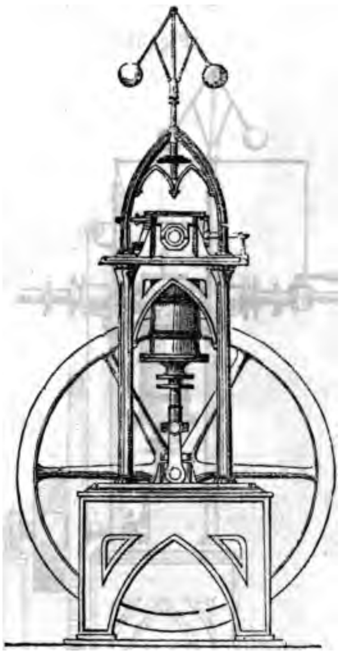
JOYCE'S PENDULOUS STEAM-ENGINE.

elevation, respectively, of the engine. The cylinder is suspend trunnions from the top, and the piston gives motion to a cran *the shafts of which* are the fly-wheel and pulley. By a band fro

latter, motion is distributed to various pulleys and shafts, by which a variety of different machines are set and kept in motion. The engine is of simple construction, and does its work well.

The principle, discovered by Woolf, of introducing steam of a high pressure into a small cylinder, and afterwards allowing it to act expansively in a larger one, adding to its effective force by condensation, is in this engine applied in an extremely ingenious and simple manner.

Fig. 35.



END ELEVATION.

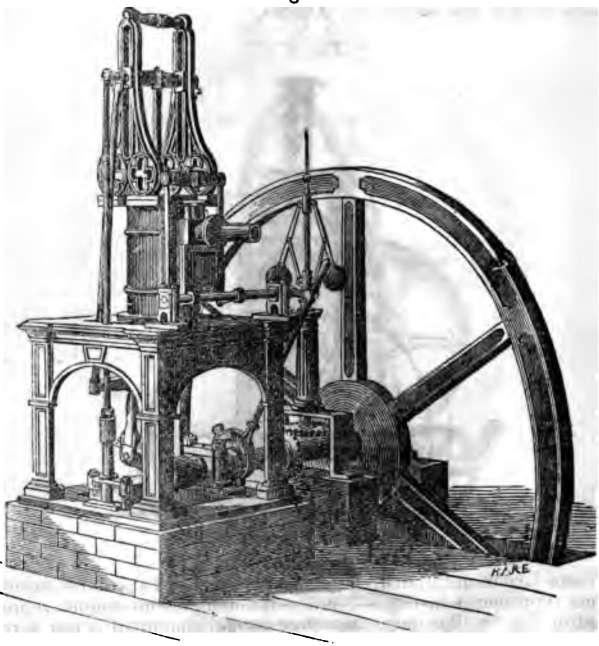
JOYCE'S PENDULOUS STEAM-ENGINE.

The cylinders are not placed before each other, as is generally done in the beam-engine, but firmly bedded and jointed side by side, forming what might be termed a double cylinder, which cylinders the inventors, upon a principle entirely new in this country, invert from their usual position, and suspend them between the framing, the trunnion-pipes or steam-ways being placed at the end, or what in

the ordinary engine would be termed the bottom of the cylinde By these means a direct motion is applied to the crank without intervention of cross-heads, side-rods, or parallel motion; the pist rod being attached to the crank-pin, the cylinders vibrating with pendulous movement on their bearings or trunnions, whilst oscillation of the cylinders works the slides by means of a bar. Th engines are capable of exerting a power of 50 per cent. more than power at which they are rated.

From the simplicity of the engine there is no risk of derangeme and the friction of the working parts is diminished three-fourt

Fig. 36.

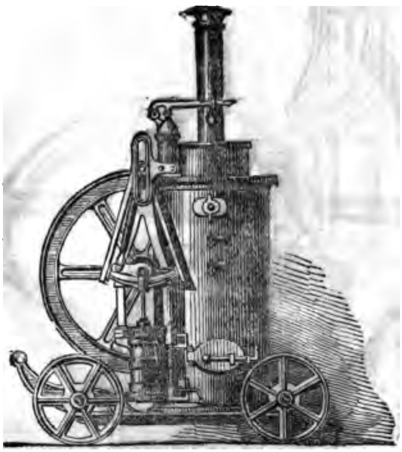


IMPROVED NON-CONDENSING EXPANSIVE TABLE ENGINE, WITH VERTIC CYLINDER.

whilst the consumption of fuel is less than 3 lb. per horse power hour, and there is a saving of one-half the space usually occupied the ordinary steam-engines. Messrs. W. Joyce and Co. first co menced manufacturing these engines in 1834, since which per they have been erected in large numbers.

Messrs. Tuxford, of Boston, exhibited an improved non-condensing table-engine, which is represented in Fig. 36, useful for driving heavy machinery, where a stationary engine is required, well adapted for barn works, chicory and woad works, flour mills up to three pairs of stones, for draining low-land from 1 to 2,000 acres, according to their level, for saw-mills, bone-mills, &c. It is fixed on a cast-iron sole plate, firmly bolted down to masonry, and can be easily removed, if required. Engines of this construction are made from two to eight-horse power, with or without governors, felted and cased, with water and pressure gauge, at from £150 to £300 each. An engine of this description has been at work in a printing-office, where it was used for driving two large cylinder machines: it answered its purpose admirably, and was seldom out of order.

Fig. 37.

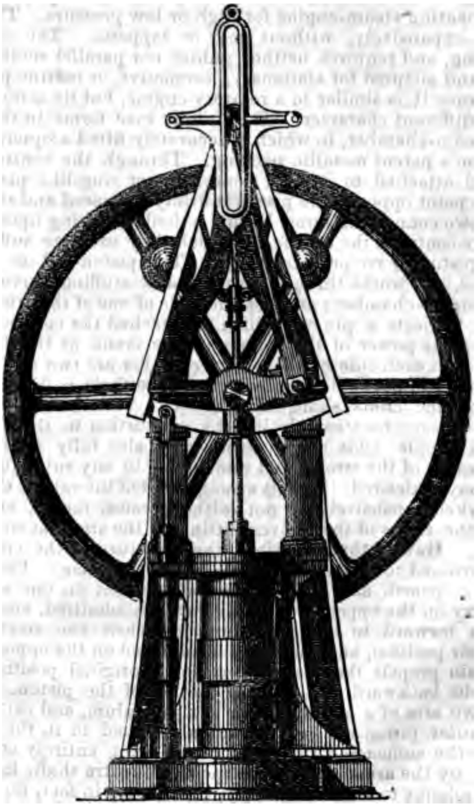


PORTABLE STEAM ENGINE.

Messrs. Lynch and Inglis, of Manchester, exhibited a portable steam-engine, represented in Fig. 37, and a stationary steam-engine, represented in Fig. 38. For purposes, where a small amount of power is required, such as crushing seeds, hoisting goods, pumping water, &c., these engines are peculiarly adapted. They are portable without sacrificing the proper proportions of their several parts; the simplicity of its construction, there being no more working parts than are absolutely necessary to communicate the required motion; and by this arrangement the strain caused by the angle of the crank is entirely removed from the piston-rod; a long connecting rod is also obtained, and the crank shaft brought down to the lowest point possible, so that the

engine may be driven at a very high velocity, and yet remain fectly steady. And, further to secure this desirable end, the wheel is nicely balanced. Another great advantage may be obse in the long slide-valve, which not only effects a saving of steam,

Fig. 38.



STATIONARY STEAM-ENGINE.

consequently of fuel also, but insures greater accuracy and durab which are points of no mean importance in an engine intended placed in the care of men not at all or very partially acquainted

the construction of steam-engines. The inside packings are all metallic, so that the trouble and annoyance of frequently taking the engine asunder is entirely avoided. The time is not far distant when the farmer, warehouseman, and shopkeeper, will call in the aid of these useful auxiliaries to perform that labour which is now but imperfectly accomplished by man.

Messrs. Bunnett and Co., of Deptford, exhibited a patent concentric reciprocating steam-engine for high or low pressure. The steam is worked expansively, without gear or tappetts. The engine is direct acting, and requires neither guides nor parallel motion; it is compact, and adapted for stationary, locomotive, or marine purposes. In appearance it is similar to a rotatory engine, but its action is of a decidedly different character. The circular case forms in the lower part the steam-chamber, in which is accurately fitted a square piston, with Barton's patent metallic packing. Through the centre of the piston, and attached to it, is a concentric or ring-like piston-rod, which at a point opposite the piston is firmly embraced and supported above by two connecting arms, having a double bearing upon a fixed shaft in the centre of the engine, on which they oscillate sufficient to allow the piston to reciprocate freely. The piston-rod is made of square steel, and works through two metallic-stuffing boxes in the top of the steam-chamber; and from the side of one of the arms above-mentioned projects a pin, to which is attached the connecting-rod transferring the power of the engine to the crank of the fly-wheel and gear. On each side of the steam-chamber are two distinct side valves, worthy of particular notice; they take their motion from an eccentric on the crank shaft, and have two slide-boxes or covers, by which means no steam is lost by exhaustion in the passages, as in the single slide; the exhaust is also fully open at the commencement of the stroke, and remains so to any subsequent part of it that may be desired. By this arrangement of the valves, the steam can be worked expansively, or not, without cams, tappet, or gear of any kind, the slides of themselves cutting off the steam at any part of the stroke. Having thus explained the structure of the engine, we will now proceed to explain the mode of its operation. The steam-valve being opened, and the exhaust-valve closed on one side, and the contrary on the opposite side, the steam is admitted, and propels the piston forward to the opposite side, when the steam-valves change their position, and the steam is admitted on the opposite side, which again propels the piston back to its original position,—and thus, by the backward and forward motion of the piston, it passes through two arcs of a circle, similar to a pendulum, and carries with it the annular piston-rod and the arms attached to it, thereby sets in motion the connecting-rod; the piston being entirely carried or suspended by the arms attached to the fixed centre shaft, is relieved from all tendency to wear irregularly, there being in fact, no pressure upon it beyond that of the springs necessary to keep the segments in their places.

By the simple arrangement and working of the engine the connecting rod has a direct action, without the intervention of guide rods or parallel motion of any kind, and during the time that the greatest force is required upon the crank, it never forms an angle of more than five

to ten degrees; its reciprocating motion describing an arc of a circle, which so nearly assimilates to the rotatory action of the crank, the changes of motion are effected with surprising ease and rapidity; and whether it be from the direct application of the force upon the crank alone, or the absence of parallel motion, or from the power being communicated as it were, upon an inclined plane, direct to the connecting rod, or by a combination of all these, very great power is gained.

The patentees have made several experiments, proving the advantages of the position of their connecting rod and crank motion over the methods now in use in locomotive and other engines. We have annexed a table of these experiments. By these it is shown that in some positions of the crank, it having just passed its centre, nearly double the power is obtained, and taking the average of the whole revolution of the crank an advantage of more than one-third is gained; the experimental engine, with a piston of 24 inches superfices and a pressure of 20lbs. only on the square inch, exhibited great power, driving several lathes, machines, &c., while without any load the crank performed upwards of 260 revolutions in a minute.

In concluding this volume, the following observations, principles, and rules, are added for the use of practical engineers, into whose hands it may happen to fall:—In all kinds of steam-engines, the length of the cylinder should be about twice its diameter, so that the steam may be bounded by the least possible quantity of surface. According to Tredgold, the velocity of the piston in feet per minute should be 98 times the square root of the length of the stroke, in an engine for raising water; and 103 times that length, in one for driving machinery. Also, the *area* of a transverse section of the steam passages should be the 4800th part of the *product* of the velocity of the piston in feet per minute, and the *area* (in feet) of a section of the cylinder parallel to its base.

In the *common* atmospheric engine, if this area be multiplied by half the velocity, and the product, by 1·23 added to 1·4 divided by the diameter, the result divided by 1480 gives the number of cubic feet of water required for steam per minute. If the difference between 1220 deg. and the temperature of condensation, be divided by the difference between that temperature and the temperature of the cold water, the quotient will be the number of times the quantity of water required for injection must exceed that required for steam, which is generally about twelve times. The aperture for injection must be such as to admit that quantity during the time of the stroke. The head of water should be about three times the height of the cylinder. When the jet apertures are square, the area of a section should be the 850th part of the area of a section of the cylinder. The diameter of the conducting pipe should be about four times that of the jet.

In the atmospheric engine with a separate *condenser*, the capacity of the air-pump should be one 14th part of that of the cylinder, or making the stroke of the air-pump half that of the steam piston, its diameter should be $\frac{3}{8}$ of the diameter of the cylinder. If the area of a section of the cylinder be multiplied by half the velocity, and to the product one-5th part be added, for loss by cooling, &c. the sum divided by 1480, gives the quantity of water in cubic feet per minute required for the boiler; and 24 times this quantity is necessary, for injection.

The diameter of the injection aperture should be one 36th part of the diameter of the cylinder, and that of the injection pipe one 9th part.

In a *Single-acting engine* on Watt's principle, the capacity of the air-pump and condenser should each be ⅛ of that of the cylinder, or their dimensions should each be half the diameter and half the length of stroke of those of the cylinder. By multiplying the area of a section of the cylinder by half the velocity, adding one-10th for cooling, &c. and dividing the sum by the volume of the steam corresponding to its force in the boiler, the quotient is the quantity of water required for steam per minute. The quantity of injection-water should be 24 times this quantity, and the diameter of the injection-pipe one 36th part of that of the cylinder.

In a *Double-Acting* engine, the proportions of the air-pump, condenser, and cylinder, should be the same as above; the quantity of water required for the steam and injection, *double*, and the proportions of the injection-pipe and cylinder the *same*. At the ordinary pressure of two pounds per circular inch on the valve, in both engines, the divisor for the volume of steam is 1497. The proportions of the dimensions of boilers are commonly stated to be, for width, 1; for depth, 1·1; and for length, 2·5; otherwise, five square feet of surface of water is allowed for each horse-power. Boulton and Watt allowed twenty-five cubic feet of space in the boiler for each horse-power.

As to the *Effective Pressure of Steam in Engines*, Mr. Tredgold estimates the loss of motive force in the *common* atmospheric engine due to the uncondensed steam (temp. 160 deg.), to the force requisite to expel it and the air from the cylinder, to the friction of the piston and axes, and to the force required to open and close the valves and raise the injection-water—at ·49 of the atmospheric pressure; hence, the effective pressure is only ·51 of this pressure, or 5·9 lbs. per circular inch. In the atmospheric engine with a *condenser*, the loss of motive force due to the same causes, with the addition of the force requisite to work the air-pump, is only ·458 of the atmospheric pressure; hence, the effective pressure is ·542 of this pressure, or 6·25 lbs. per circular inch.

In the *Single-Acting* engine, the lost of motive force due to the same causes is ·402 of the pressure of one atmosphere: hence, the effective pressure is ·598 of this pressure. To determine the mean effective pressure when the force of the steam in the boiler is different from that of the asmosphere:—Multiply the given pressure in inches of mercury by ·598, and from the product subtract the pressure due to the temperature of the uncondensed steam, the remainder is the pressure required, in inches of mercury; multiply this pressure by 14¾ lbs. the atmospheric pressure on a square inch, and divide the product by 30, the quotient is the mean effective pressure on a square inch of the piston, which multiplied by ·7854 gives the pressure per circular inch.

In the double-acting engine, the loss of motive force due to the causes above-mentioned, is estimated by Mr. Tredgold at ·368 of the pressure of one atmosphere; hence, the effective pressure is ·632 of this pressure. Consequently the mean effective pressure on the piston, when the force of the steam in the boiler is different from that

of the atmosphere, is found by the rule in the preceding paragraph. The force of low pressure steam in the boiler, is generally equivalent to that of 35 inches of mercury, the temperature being 220 deg.; and the temperature of the uncondensed steam 120 deg., its force being equivalent to that of 3·7 inches. Hence, for the single engine, we have $35 \times \cdot 598 = 20 \cdot 93$ inches, and $20 \cdot 93 - 3 \cdot 7 = 17 \cdot 23$ inches; whence $17 \cdot 23 \times 14 \cdot 75 = 254 \cdot 1425$, and $254 \cdot 1425 \div 30 = 8 \cdot 47142$ lbs. nearly, per square inch; consequently $8 \cdot 47142 \times \cdot 7854 = 6.66$ lbs. nearly, per circular inch. For the double engine, we have $35 \times \cdot 632 = 22 \cdot 12$ inches and $22 \cdot 12 - 3 \cdot 7 = 18 \cdot 42$ inches; whence $18 \cdot 42 \times 14 \cdot 75 = 271 \cdot 695$, and $271 \cdot 695 \div 30 = 9 \cdot 0565$ lbs. per square inch; consequently $9 \cdot 0565 \times \cdot 7854 = 7 \cdot 1$ lbs. per circular inch.

To Calculate the Power of a Steam-engine.—1. *The Common Atmospheric Engine* —Multiply 5·9 times the square of the diameter of the cylinder in inches by half the velocity of the piston in feet per minute, and the product is the effective power in lbs. raised one foot high per minute. Divide this product by 33000, and the quotient is the number of horses' power. 2. *The Atmospheric Engine with Conductor.*—Apply the same rule, but, instead of 5·9, use 6¼ for the multiplier. 3. *Single-Acting Engine.*—Multiply the mean effective pressure on the piston by the square of its diameter in inches and by half the velocity in feet per minute, and the product is the effective power in lbs. raised one foot high per minute. The number of horses' power is found as above. 4. *Double-Acting Engine.* Apply the preceding rule, but instead of half the velocity, use the whole of it, for a multiplier.

To Calculate the Power of an Engine when the Steam Acts Expansively.—1. In the *Single-Acting Engine.*—Multiply 2·3 times the common logarithm of the reciprocal of the fraction denoting the portion of the stroke made when the steam is cut off, and to the product add ·3; then multiply the sum by that fraction, and by the whole force of the steam in the boiler, in lbs. per circular inch; the product is the mean effective pressure on the piston, with which proceed as before directed. 2. In the *Double-Acting Engine.*—Divide 2·3 times the common logarithm of the reciprocal of the fraction denoting the portion of stroke made when the steam is cut off, by the reciprocal itself, and multiply the quotient by the whole force of the steam in the boiler, in lbs. per circular inch, the product is the mean effective pressure on the piston, with which proceed as directed before.

To calculate the Power of a High Pressure Engine.—The excess of the force of steam in the boiler above the pressure of the atmosphere, as shown by the steam-guage, is the motive force, but the loss of force due to friction, waste, cooling, opening of valves, cutting off steam before the end of the stroke, &c., is estimated by Mr. Tredgold at ·4 of the force of the steam in the boiler, consequently the effective pressure is only ·6 of this force diminished by the pressure of the atmosphere. Hence, *when the engine is working at full pressure*, multiply the difference between six-tenths of the excess of the force of steam in the boiler above the pressure of the atmosphere, and four-tenths of that pressure, in pounds per circular inch, by the square of the diameter of the cylinder in inches, and by the velocity of the piston

n feet per minute, and the product is the number of lbs. raised one oot high per minute, from which the number of horses' power may e found as before. If the area of the piston in feet be multiplied by he velocity per minute in feet, the product will be the volume of team when of the same density as that in the boiler; if this product e divided by the volume of steam which a cubic foot of water forms t the temperature or force in the boiler, the quotient is the cubic eet of water consumed per minute.

When the Engine is Working Expansively.—1. *To find the mean ffective pressure on the piston,* add 1 to 2·3 times the logarithm of the eciprocal of the fraction denoting the part of the stroke at which the team is cut off, divide the sum by that reciprocal, and subtract ·4 rom the quotient; multiply the remainder by the whole force of the team in the boiler per circular inch, and from the product subtract 1·55 for the pressure of the atmosphere; the remainder is the mean ffective pressure in lbs. per circular inch. 2. *To find the Power.*—Multiply the mean effective pressure by the square of the diameter of he piston in inches and by the velocity in feet per minute; and from he product, find the number of horses' power, as before. If the area f the piston be multiplied by the velocity in feet per minute, and the roduct, increased by one-tenth part, be divided by the reciprocal of he fraction above mentioned, the quotient is the quantity of steam in ubic feet consumed per minute; from this quantity the number of ubic feet of water required may be found as before.

Length of Stroke and Velocity of an Engine.—The stroke of an engine s equal to one revolution of the crank shaft, and, consequently, to louble the length of the cylinder. In common parlance, however, he length of stroke and the length of the cylinder are synonymous; n this sense it is to be understood in the following rules, by Tredgold, for finding the proper velocity of the piston: 1. If the engine e regulated by a fly, and the pressure on the piston be the same hroughout the stroke, the best velocity is 120 times the square root f the length of the stroke in feet. 2. If the steam act expansively, he velocity is found by multiplying the logarithm of the reciprocal f the fraction denoting the part of the stroke where the steam is ut off, by 2·3, adding ·7 to the product, and multiplying the um by that fraction, then taking 120 times the square root f the product. 3. If the steam does not act expansively, the elocity is equal to 103 times the square root of the length of he stroke. 4. If the steam act expansively at the ordinary preure of about 8 lbs. per circular inch of the safety valve, and the steam s cut off at half the stroke, the velocity is 100 times the square root f the length of the stroke.

The following table, which was referred to in a preceding chapter, hows the elasticity of steam at high pressures varying from one to fty atmospheres, and the temperatures corresponding to these presures, according to the degrees marked on Fahrenheit's thermometer. t is calculated exactly from one given by Messrs. Dalong and Arago, n the report of their experiments on steam made to the Institute of 'rance. The results of these experiments are considered to be the nost careful and extensive that have ever been made.

The columns marked *At.* contain the ***elasticity or force of steam in atmospheres***, and the columns marked *Temp.*, on the right, contain the ***corresponding temperatures in degrees of*** Fahrenheit's thermometer.

At.	Temp.	At.	Temp.	At.	Temp.	At.	Temp.	At	Temp.
1	212°·00	7	331°·70	18	408°·92	30	457°·16	42	491°·76
1½	233 ·96	7½	336 ·86	19	413 ·96	31	460 ·45	43	494 ·27
2	250 ·52	8	341 ·96	20	418 ·46	32	463 ·64	44	496 ·72
2½	263 ·84	9	350 ·78	21	422 ·96	33	466 ·74	45	499 ·14
3	275 ·18	10	358 ·88	22	427 ·28	34	469 ·78	46	501 ·50
3½	285 ·08	11	367 ·34	23	431 ·42	35	472 ·73	47	503 ·85
4	293 ·72	12	374 ·00	24	435 ·56	36	475 ·64	48	506 ·16
4½	301 ·28	13	380 ·66	25	439 ·34	37	478 ·46	49	508 ·40
5	308 ·84	14	386 ·94	26	443 ·16	38	481 ·24	50	510 ·60
5½	314 ·24	15	392 ·86	27	446 ·82	39	483 ·95	51	512 ·80
6	320 ·36	16	398 ·48	28	450 ·38	40	486 ·59	52	514 ·82
6½	326 ·26	17	403 ·[illegible]2	29	453 ·82	41	489 ·21	53	517 ·08

THE END.